ESSENTIALS OF ELECTRICITY

AN INTRODUCTORY TEXTBOOK FOR SCHOOL AND SHOP

DIRECT CURRENTS

BY

W. H. TIMBIE

Professor of Electrical Engineering and Industrial Practice
Massachusetts Institute of Technology

SECOND EDITION, REWRITTEN

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PREFACE TO THE SECOND EDITION

In the eighteen years since the first edition of this text, many changes have taken place in the field of electrical engineering. New applications of electricity have been made to practically all formerly existing industries, and entirely new industries and processes have come into being. Even the fundamental theory of electrical science has undergone decided changes.

This second edition introduces the modern electron theory, to explain the action of such appliances as the vacuum tube with its application to radio and wire communications, and to rectifier circuits. A new chapter on electrical meters and instruments and their uses has been included.

The problems, upwards of 650 in number, form an important part of the text and have all been carefully revised and many new ones added. The data and applications both in the problems and in the text material are in accordance with best modern practice and refer to apparatus which the student is most likely to meet on the job.

I wish to express my indebtedness and gratitude to my colleague, Professor Karl L. Wildes, who undertook the burden of the revision. He has brought to the work an unusual fund of theory combined with practical experience, as well as the ability to express his ideas clearly and concisely.

W. H. Timbie

Cambridge, Mass.
June, 1931

PREFACE TO THE FIRST EDITION

The following brief text was developed from notes which the author has been using in short trade courses for students who wish to enter or to advance themselves in one or another of the electrical trades. It attempts to explain the underlying facts and laws of good electrical practice, which the really well-informed and efficient workman must understand, rather than to provide book descriptions of the mechanical operations of the electrical trades, which can be really learned only through continued practice in their performance. It is designed to be a systematized text for class and self-instruction, and, also, a book of electrical information to which frequent reference may be made during the day's work. For convenience in the latter purpose, it is bound in a pocket size and with semiflexible covers.

As is implied in the title, only such material has been included in the text as is regarded to be absolutely essential to the object in view. The order in which the various topics are taken up is that which the author has found to be most teachable. The method of presentation is designed both to arouse and hold interest, and to furnish the easiest approach to new or more difficult ideas. For this reason, the author's plan is to build outward, and by very small steps, from the starting point of the reader's own experience in the commercial shop or the school laboratory. Students in short trade courses must acquire a large fund of information in an extremely short time. This cannot be accomplished by increasing the size of the mental steps the student must take, but rather by shortening and by

properly arranging these steps, until he can pass most surely and rapidly from one conception to the next in order. In this connection, the numerous simple diagrams and the large number of direct and practical problems to be found in the book will prove most helpful.

In conclusion, I wish to take this opportunity to express my appreciation and thanks to Mr. Arthur L. Williston, Principal of Wentworth Institute, and Mr. J. M. Jameson, Pratt Institute, for the incentive and valuable aid which they have rendered throughout the preparation of this text. Grateful acknowledgment is also extended to my colleagues, Prof. H. H. Higbie and Mr. W. J. Mayo, for many valuable criticisms and suggestions.

W. H. TIMBIE

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EDITOR'S NOTE

The fundamental requisites for a really good textbook in any applied subject, or for a really good reference book for self-instruction, are: first, that it shall contain all of the more important facts and principles required by its readers; and second, that this information and theory shall be presented clearly and forcibly, unclouded by a mass of irrelevant matter. The strength of this short text lies in the satisfactory manner in which it meets both of these conditions. It is a book which supplies the underlying reasons, the "whys" of his task, which constantly present themselves to the intelligent "man on the job."

Mr. Timbie was selected to write the text of the Technical Series designed for the use of men in the electrical contracting business and allied electrical trades, not merely because of his intimate knowledge of industrial electricity, but also because of his well-known ability to present information in an unusually clean-cut and effective way. Those who are familiar with the "Elements of Electricity" by the same author have recognized this gift for clear and convincing expression. This more applied text is put forth with the belief that it will prove equally successful in its particular field.

THE EDITOR

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ESSENTIALS OF ELECTRICITY

CHAPTER I

OHM'S LAW

1. The Flow of Electricity. Electricity, in motion, lights lamps, drives motors, actuates communication and signaling devices, decomposes chemical compounds, and produces heat in electric furnaces and in many types of smaller appliances such as soldering irons, stoves, hair wavers, and heating pads. Electricity, at rest, has fewer and less familiar practical applications. Accordingly, our study here will be confined largely to electricity at work, that is, in motion.

We shall have something to say about the nature of electricity in Chapter VIII but for the present let us think of it as something that flows in wires somewhat as water flows in pipes, something whose quantity can be measured in units called coulombs as quantities of water are measured in units called gallons. It may be caused to move or flow through a conductor by the application of a pressure and its progress may be made relatively difficult or easy according to the kind of conductor through which it flows. The sooner we become familiar with this idea of flow of electricity, the sooner will we get a firm grasp of the subject.

We have to consider, then, three things:

(*a*) Current (the flow of electricity along a conductor).
(*b*) Pressure (that which causes the current to flow).
(*c*) Resistance (that which regulates the flow of current).

We are all more or less familiar with the flow of water through pipes and the simple facts governing this flow. Accordingly,

we can help to make real our knowledge of the flow of electric currents along conductors by calling to mind the many points of resemblance to the flow of water.

2. (a) Current. Ampere. In the first place, when water is flowing through a pipe we never ask, "How much water is there in the pipe?" but rather, "How much current is flowing through the pipe?" That is, "How much water flows through the pipe in a given time?" The answer would not be "Five gallons," but "Five gallons per second." We are interested not in quantity, but in quantity that passes through in a second.

Similarly, we never ask, "How much electricity is there in that wire?" but rather, "How much current is flowing along that wire?" By which question we mean, "How much electricity flows along that wire per second?" The answer could not be "Five coulombs," but it might be "Five coulombs per second." We are interested not in the quantity, but in the quantity that passes in a second.

Now a **coulomb of electricity** is just as definite a quantity of electricity, as a **gallon** is a definite quantity of water, coulomb being the name given to the unit in which quantity of electricity is measured.

It is unfortunate that we have no name for the unit flow of water, which means one gallon per second. Consequently we always have to say five gallons per second, ten gallons per second, etc.

But we are fortunate in not having to use the term "coulomb per second" to denote quantity of electricity that flows per second. We call this "**coulomb per second**" an **ampere.** Instead, therefore, of answering the above question by, "Five coulombs per second," we would say, "Five amperes." Thus we do not need to say "per second" each time, as "amperes" means "coulombs per second." So ten amperes means ten coulombs per second, etc.

Since we are always concerned with the flow of electricity

and not the quantity, we employ continually the term **ampere** and rarely use the term **coulomb.**

Thus an ordinary incandescent lamp, with a tungsten filament, when glowing at rated voltage, may take a current of ½ ampere; that is, ½ ampere or ½ coulomb per second is flowing through the filament.

3. (b) Pressure (that which causes a current to flow). Volt. When a current of water flows through a pipe, we know that it flows because there is some pressure exerted on it, which causes it to flow. We say that in certain parts of the town the water comes to the houses under a pressure of 30 lbs. per sq. in. If one happens to live near the reservoir or pumping station, the pressure is likely to be higher than that at some distant point.

Similarly, when an electric current flows along a conductor, we know that it is caused to flow by some electric pressure. If we live near the generating station the pressure is likely to be higher than if we live at some distance. Thus the current through an incandescent lamp is made to flow by maintaining a pressure across the lamp. Ordinarily this is about 110 volts. When the lamp is turned on, it simply means that this pressure is allowed to act and force the ½ ampere of current through the filament of the lamp — just as turning on the valve allows the 30 lbs. per sq. in. pressure to act and to force ½ gallon per second through a water pipe. The 110 volts electric pressure does exactly the same thing to the electric current that the 30 lbs. per sq. in. water pressure does to the current of water. Just as the pounds per square inch (pressure) cause the gallons per second to flow, so the **volts** (pressure) cause the **amperes** (current) to flow.

It is essential to get the idea of amperes as current and volts as pressure clear at the very start. We can then avoid such mistakes as the following: When the statement is made that across the terminals of a switch there are 110 volts,

we often hear an uninformed person ask, "How many amperes are there?" If the switch is thrown off, there isn't any current flowing and of course there are no amperes, any more than there would be a current flowing in a pipe if the valve were turned off. Even though there were 100 lbs. per sq. in. pressure in the pipe we would not ask how much current flows, knowing well that it depends on whether or not we turn on the valve. Even then the current depends upon what is connected in the pipe line. So in an electric circuit, even if the volts pressure is known, the current depends upon whether or not the switch is thrown on, and then also upon what is connected in the line for the current to flow through.

Fig. 1 (a) and (b) shows similar hydraulic and electric circuits. In Fig. 1 (a) *g* is a centrifugal pump which keeps

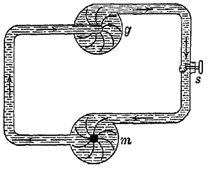


FIG. 1 (a). Hydraulic circuit containing pump, motor, and valve.

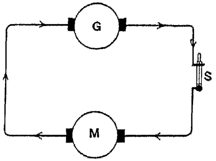


FIG. 1 (b). Electric circuit containing generator, motor and switch.

a pressure on the water in the pipe line. When valve *s* is closed, no current of water can flow through the pipe line, but when the valve is opened, this pressure forces a current of water through the circuit including the water motor *m*. In Fig. 1 (b) *G* is an electric generator which keeps an electric pressure on the electricity in the wire line. When the switch *S* is open, no current of electricity can flow through the wire line, but when the switch is closed, this pressure

forces a current of electricity through the circuit including the electric motor M. Note that closing the valve is like opening the switch since each action opens the circuit.

In Fig. 2 there are 110 volts pressure across the terminals A–B when the machine is being driven at the proper speed. There may or there may not be any current flowing to and

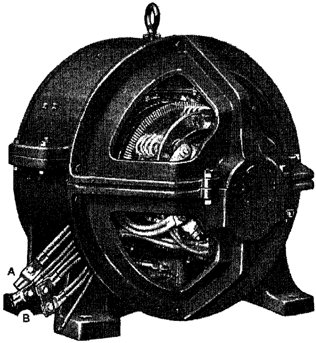


FIG. 2. Crocker-Wheeler generator showing terminals.

from these terminals. The pressure is maintained as long as the machine is running, so that a current may be drawn from the machine if desired.

Again, we read in newspaper accounts of an accident, that a man was injured by so many volts passing through his body. This is not so. The volts merely caused a certain current (amperes) to flow through the person's body and this current injured the man. We might as well have said that so many pounds per square inch passed through him, as to say so many volts went through him. These examples

are given in order that the student may, at the very outset, get a clear understanding of the meaning of **volt** and **ampere** and may avoid an incorrect use of them.

4. (c) Resistance (that which regulates the current). Ohm. We have seen that if we put a certain incandescent lamp with a tungsten filament on a circuit where the pressure is 110 volts, $\frac{1}{2}$ ampere flows through the lamp. Lamps designed for the same pressure differ in size, however, and if the lamp just mentioned does not give enough light, it may be necessary to select one which takes a larger current, say 2 amperes. The second lamp must have, then, a smaller **resistance** since it allows the same pressure to force more current through it. **Resistance** may then be defined as the property of a body which resists or limits the flow of electricity through it. It is similar to the friction in a pipe.

When a pressure of 1 **volt** can force 1 **ampere** of current through a wire, we say that the resistance of the wire is 1 **ohm.** If 1 volt can force only $\frac{1}{2}$ an ampere through a wire, we say that the resistance is 2 ohms. In order to force 1 ampere through 2 ohms resistance, it would be necessary to apply 2 volts pressure.

This agrees with what we know about the flow of water through pipes. If the pipe is small and rough, we know that it offers a large resistance to the flow of water through it, and a high pressure is necessary to force much current through it.

Similarly, if a wire is small and ill-suited for carrying an electric current, we find that its resistance is large, and that a great pressure (volts) is needed to force much current (amperes) through it.

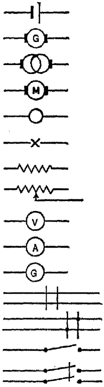
The following table will aid in fixing the meaning of the three terms discussed above. The student should study this table until thoroughly familiar with the meaning of the terms **amperes, volts** and **ohms.**

Units of	Water	Electricity
Quantity	Gallon	Coulomb
Current Quantity per second	Gallon per second	Ampere Coulomb per second
Pressure	Pound per sq. in.	Volt
Resistance	No unit	Ohm

5. Symbols. In representing the different parts of an electric circuit it is customary to use certain symbols to indicate certain electrical pieces, as for instance — X — represents an arc lamp and  represents a direct-current generator. The following table contains some of these standard symbols.

SYMBOLS

Battery cell
Generator, d-c.,
Generator, a-c.,
Motor, d-c.,
Incandescent lamp
Arc lamp
Resistor (fixed)
Resistor (adjustable)
Voltmeter
Ammeter
Galvanometer
Wires (not joined)
Wires (joined at dots)
Switch (single-pole)
Switch (double-pole)



Volts
Ampe

Figs. 1 and 3 illustrate the use of some of these symbols in circuit diagrams.

An electric current is always thought of as flowing from a higher to a lower level. We mark the higher level + (called **positive or plus**), and the lower − (called **negative** or **minus**), in order to denote in what direction the current is flowing. Sometimes arrowheads are also put on the wire. The current always flows *from the + to the −*. A given point is then + to all points below its level, and − to all points above its level. In Fig. 3 the long line of the battery cell represents the plus terminal and the short heavy line, the negative terminal. The current thus flows from A to C along the upper line.

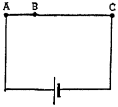


Fig. 3. Diagram of circuit containing battery cell.

If then we are considering points A and B, the point A would be + and the point B −. But if we are considering B and C, B would then be + and C −.

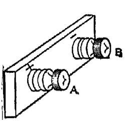


Fig. 4. Terminals of an electric circuit.

Or in Fig. 4 consider the terminals A and B, across which an electric pressure is maintained. Since A is marked +, it means that the current will flow from A and around to B, along any resistance circuit connected between the two points.

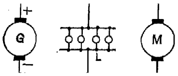


Fig. 5. Circuit diagram showing lamps and motor supplied by generator.

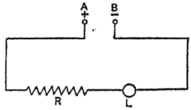


Fig. 6. Diagram of electric circuit.

The terminals on all d-c. instruments are marked in this way, in order to indicate that the + terminal is always to be connected to the higher level of the circuit.

Fig. 5 represents a d-c. generator lighting a bank of 4 in-

candescent lamps (L) and driving a motor (M). The current is flowing from the generator along the top of the circuit to the lamps and motor.

Sometimes merely the terminals of the source of the power are shown as A and B, in Fig. 6.

A = power terminal; R = resistance;

B = power terminal; L = incandescent lamp.

The current comes from A, goes through R, then L, and finally leaves at B.

6. Ohm's Law. Current. We have seen that if a certain current of electricity flows in a circuit, it flows because a certain pressure forces it to flow, and that the amount of the current is limited by the resistance of the circuit. If the pressure is 1 volt, and the resistance 1 ohm, then 1 ampere current flows. If we wish to limit this current to $\frac{1}{4}$ ampere, then all we have to do is to make the resistance 4 times as much, or 4 ohms. That is, if the pressure is 1 volt and the resistance 4 ohms then only $\frac{1}{4}$ ampere flows. **Note that by dividing the pressure (1 volt) by the resistance (4 ohms), we obtain the current ($\frac{1}{4}$ ampere).**

Suppose, now, that the resistance of a circuit is 1 ohm and we wish to send 10 amperes through it. Since 1 volt will send 1 ampere through this 1-ohm resistance, to send 10 amperes through it would require 10×1 volt, or 10 volts. That is, if the voltage is 10 volts and the resistance 1 ohm, then 10 amperes flow. **Note that the current (10 amperes) may be found by dividing the pressure (10 volts) by the resistance (1 ohm).**

Suppose, again, that in this circuit with the 10 volts pressure and 1-ohm resistance, we wish to limit the current to 5 amperes, instead of to 10 amperes. Since 10 volts can force just 10 amperes to flow through 1-ohm resistance, if we double the resistance, then 10 volts can force just one-half the current, or 5 amperes, through the circuit; that is,

if the pressure is 10 volts and the resistance 2 ohms, then a current of 5 amperes flows.

Note again that the current (5 amperes) may be found by dividing the voltage (10 volts) by the resistance (2 ohms). In fact, the current which a given pressure will force through a given resistance can always be found by dividing the pressure (in volts) by the resistance (in ohms). This fact is usually stated as a great general law and is called **Ohm's Law**, after the man who first stated it.

OHM'S LAW

The current which an electric pressure forces through a resistance equals the pressure divided by the resistance.

This may be written briefly:

$$\text{Current} = \frac{\text{pressure}}{\text{resistance}};$$

or

$$\text{Amperes} = \frac{\text{volts}}{\text{ohms}}.$$

Example 1. How much current flows through an incandescent lamp which has a resistance (hot) of 27.5 ohms when used on a 110-volt line?

$$\text{Amperes} = \frac{\text{volts}}{\text{ohms}} = \frac{110}{27.5} = 4 \text{ amperes}.$$

Example 2. An electric soldering iron has a resistance (hot) of 2.5 ohms. What current will it take when used on a farm-lighting circuit maintaining a pressure of 30 volts?

$$\text{Amperes} = \frac{\text{volts}}{\text{ohms}} = \frac{30}{2.5} = 12 \text{ amperes}.$$

Prob. 1-1. What current can 100 volts force through 5 ohms?

Prob. 2-1. How many amperes would be required for an electric laundry iron having 22 ohms resistance if it operates on 110 volts?

Prob. 3-1. An electric toaster is designed for operation on 110 volts. What current will it take if its resistance is 20 ohms?

Prob. 4-1. An electroplating dynamo generates 6 volts; the resistance of the circuit is 0.2 ohms. What is the current?

Prob. 5-1. A dry cell has a terminal voltage of 1.3 volts when a wire of 0.325 ohm is placed across its terminals. What current flows in the wire?

Prob. 6-1. A battery of dry cells having a terminal voltage of 3 volts is placed directly across the filament of a radio vacuum tube having a resistance of 50 ohms. What is the filament current?

Prob. 7-1. What filament current is taken by a vacuum tube whose filament has a resistance of 4.8 ohms and operates on 1.2 volts?

Prob. 8-1. What current would flow through the coils of an electric bell having a resistance between terminals of 150 ohms when operated on a 6-volt storage battery?

Prob. 9-1. The resistance of a certain tungsten lamp when cold is 20 ohms. What will the current be the instant it is placed across a 110-volt line?

Prob. 10-1. The resistance of the lamp of Prob. 9-1 rises to 84 ohms when glowing at full brilliancy. What will be the final steady current of this lamp?

Prob. 11-1. An electric car heater has a resistance of 100 ohms. What current flows in the heater when the trolley car is in such a position that a pressure of 525 volts exists across the heater terminals?

Prob. 12-1. A certain reel of rubber-insulated cable when placed in a tank of conducting liquid has a resistance of 4,000,000,000 ohms between the conductor of the cable and a plate immersed in the liquid. What current flows through the insulation when 300 volts are impressed on this cable?

7. Measurement of Current. Ammeter. If we wish to measure the current of water which is flowing through a pipe, we insert a flowmeter into the pipe as (*A*) in Fig. 7. The current of water flowing through the pipe also flows through the flowmeter and causes it to indicate the number of gallons per second which pass through it. We can't

attach an instrument to the outside of the pipe and find the current through the inside. We must open up the pipe and insert the instrument into the line so that the current which we wish to measure tends to flow directly through the instrument. Fig. 8 shows a water flowmeter of modern type. The terminals are inserted into the pipe, so that the current of water tends to flow through the meter.

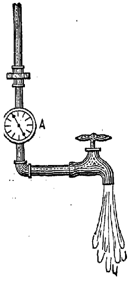


FIG. 7. The water meter *A* measures the flow of water through the pipe.

In the same way, if we wish to measure the current of electricity which is flowing through an electric circuit we insert a current meter into the circuit, so that all the current which we wish to measure flows through the meter.

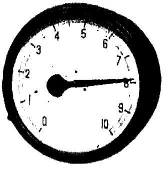


FIG. 8. General Electric flowmeter.

Since an instrument which measures an electric current must read in amperes, such a current meter is called an ammeter (a contraction of the term ampere-meter). Fig. 9 represents an ammeter (*A*) inserted in a line to measure the current flowing through the incandescent lamp (*L*). Note that all the current which goes through the lamp must pass through the ammeter. The ammeter then must be of very low resistance in order not to hinder the current. Such an instrument is very delicate and must be handled carefully.

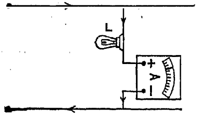


FIG. 9. The ammeter *A* measures the electric current flowing through lamp *L*.

A fuller description showing the principles upon which it operates is to be found in Chapter X. Sufficient practice in the use of this instrument should be gained by the student before proceeding further with the work.

Note that the terminals of the ammeter are connected so that the current enters the meter at the plus (+) and leaves it at the negative (−) terminal.

8. Ohm's Law. Voltage. It may be desired at times to find the voltage required to force a certain current through a certain resistance. We have seen that it requires 10 volts to force 10 amperes through 1 ohm. Now, if we wished to force the 10 amperes through 2 ohms it would require 2×10 volts, or 20 volts. **Note that the voltage required is the product of the current (10 amperes) times the resistance (2 ohms).**

Now suppose that we wish to force 5 times as much current, 50 amperes, through the 2 ohms. It would require just 100 volts or 5 times as much voltage. **Note again that the pressure (100 volts) is the product of the current (50 amperes) times the resistance (2 ohms).** This fact may be stated as a general law as follows:

> **The pressure required to force a given current through a given resistance is the product of the current times the resistance.**

$$\textbf{Pressure} = \textbf{current} \times \textbf{resistance},$$

or

$$\textbf{Volts} = \textbf{amperes} \times \textbf{ohms}.$$

Example 3. The hot resistance of an incandescent carbon lamp is 220 ohms. It requires $\frac{1}{2}$ ampere to cause it to glow. What voltage must be impressed across it?

$$\text{Voltage} = \text{amperes} \times \text{ohms}.$$
$$\text{Voltage} = \tfrac{1}{2} \times 220 = 110 \text{ volts}.$$

Example 4. To ring a certain electric bell requires $\frac{1}{4}$ ampere. The resistance of the coils in the bell is 12 ohms. What voltage is required?

$$\text{Voltage} = \text{amperes} \times \text{ohms.}$$
$$\text{Voltage} = \tfrac{1}{4} \times 12 = 3 \text{ volts.}$$

Prob. 13–1. What voltage will produce a current of 10 amperes through 100 ohms resistance?

Prob. 14–1. What pressure is needed to light the filament of a vacuum tube if its resistance is 5 ohms and its current is 1 ampere?

Prob. 15–1. A megohm is 1,000,000 ohms. How many volts are necessary to cause a current of 0.003 ampere through a resistance of 50 megohms?

Prob. 16–1. An electric bell has a resistance of 800 ohms and requires 0.03 ampere to ring. What is the smallest voltage that will ring the bell?

Prob. 17–1. What voltage must be used to operate a telephone receiver having a resistance of 1000 ohms and requiring 0.003 ampere?

Prob. 18–1. A miniature incandescent lamp requires 1.1 amperes to make it glow. Its resistance is 5 ohms. What voltage is required?

Prob. 19–1. What pressure exists across a neon lamp of 10,000 ohms resistance when 0.02 ampere flows through it?

9. Measurement of Pressure. Voltmeter. When we wish to measure the water pressure in a pipe, we tap a pressure gage on to the pipe line, as (*A*) in Fig. 10. Note that no current flows through the gage. It is merely tapped on to the pipe at the point at which we wish to measure the pressure, so that the pressure can get at it and cause it to indicate. The pipe, and current flowing through it, are not disturbed. Similarly, when we wish to measure the electric pressure causing an electric current to flow through, say a lamp, we do not disturb the circuit nor the current flowing

through it. We just tap the terminals of a voltmeter on to the line, as in Fig. 11. We want to measure the pressure forcing the current through the lamp, so we tap the voltmeter leads on the terminals of the lamp. Note that the current which flows through the lamp does not go through the voltmeter. The voltmeter is not made to register current but pressure, and there is no need for the current to go through it, but it must be placed so that the pressure across the lamp is also across the voltmeter, the (+) side of the voltmeter being connected to the (+) side of the lamp. This pressure causes it to indicate the volts and not the current. Note that the method of connecting a voltmeter is quite different from the method of connecting an ammeter. An ammeter is inserted into the circuit, and becomes a part of the circuit, and receives the full current of the circuit. A voltmeter is merely tapped on to the circuit, and does not become a part of the circuit, nor does it receive the current which is flowing through the circuit. Great care must be used not to tap on an ammeter by mistake. An ammeter tapped on to a line in place of voltmeter is instantly ruined by the great rush of current.

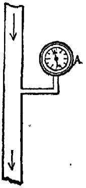


FIG. 10. The pressure gage *A* indicates the pressure of the water in the pipe.

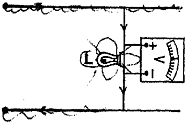


FIG. 11. The voltmeter *V* measures the pressure across lamp *L*.

10. Ohm's Law. Resistance. At times we wish to limit the current in a piece of apparatus to a certain number of amperes. If the pressure is known, it then becomes necessary to compute the resistance which will allow just this desired amount of current to flow, when the pressure is

applied. We have seen that when the pressure is 10 volts and the resistance is 1 ohm, a current of 10 amperes flows. If we wish to limit the current to $\frac{1}{2}$ of 10 or 5 amperes, we must double the resistance and use 2 ohms. That is, 10 volts can force just 5 amperes through 2 ohms. **Note that the resistance (2 ohms) equals the pressure (10 volts) divided by the current (5 amperes).** If the pressure had been 20 volts we should have had to use a resistance of 4 ohms to keep the current down to 5 amperes. **Note again that the resistance necessary (4 ohms) is equal to the pressure (20 volts) divided by the current (5 amperes).** The general law for this fact is stated as follows:

> **The resistance through which a given pressure will force a given current equals the quotient of the pressure divided by the current.**

$$\text{Resistance} = \frac{\text{pressure}}{\text{current}}.$$

$$\text{Ohms} = \frac{\text{volts}}{\text{amperes}}.$$

Example 5. What resistance must an electric heater have, if it is to be used on 550 volts and is to take 4 amperes?

$$\text{Resistance} = \frac{\text{pressure}}{\text{current}}.$$

$$\text{Resistance} = \frac{550}{4} = 137.5 \text{ ohms.}$$

Example 6. An arc lamp which takes a current of 6 amperes is to be used on a 110-volt circuit. What resistance must it have?

$$\text{Resistance} = \frac{\text{pressure}}{\text{current}}.$$

$$\text{Resistance} \quad 110 = 18.3 \text{ ohms.}$$

Prob. 20-1. An incandescent lamp uses 0.55 ampere on a 110-volt circuit. What is the resistance of the lamp when burning?

Prob. 21-1. Through what resistance will 230 volts force 30 amperes?

Prob. 22-1. What is the resistance of the heating element of an electric soldering iron designed to take a current of 2.1 amperes on a 110-volt circuit?

Prob. 23-1. What is the resistance of a vacuum-tube filament which takes 0.25 ampere at 1.3 volts?

Prob. 24-1. The voltage across a certain piece of apparatus was found to be 38.7 volts. The current flowing through it was 3.1 amperes. What was its resistance?

Prob. 25-1. What resistance must the motor of Fig. 12 have if it takes 5.2 amperes when starting on a 230-volt line?

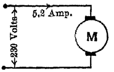


FIG. 12. Motor connected to 230-volt source.

Prob. 26-1. What resistance must the coils of an electric bell have to limit the current to 0.03 ampere when used on a 6-volt storage battery?

Prob. 27-1. What is the resistance of an ammeter if the voltage across it is 0.2 volt when it indicates 10 amperes?

Prob. 28-1. What is the resistance of a voltmeter which indicates 230 volts when it takes a current of 0.02 ampere?

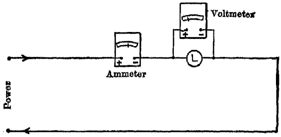


FIG. 13. "Ammeter and Voltmeter" method of measuring resistance of lamp.

11. Measurement of Resistance. Voltmeter and Ammeter Method. It can be seen from the above discussion that when we wish to find the resistance of an electrical piece, we have merely to measure the current which a known voltage can force through it, and divide the voltage by the current.

SUMMARY OF CHAPTER I

ELECTRICITY may be considered to flow as a current along a conductor, very much as water flows through a pipe.

THE CURRENT of electricity is measured in AMPERES, which state the QUANTITY passing through conductor IN ONE SECOND.

THE PRESSURE which causes the current to flow is measured in VOLTS. Corresponds to "pounds per square inch."

THE RESISTANCE which a conductor offers to the current is measured in OHMS. Corresponds to the FRICTION in a pipe.

When two points of an electric circuit are marked, one (+) and the other (−), it always indicates that the current is considered to flow along the conductor from the (+) to the (−).

OHM'S LAW states the relation which exists among current, pressure and resistance. It is written in THREE forms.

1. $\text{Amperes} = \dfrac{\text{volts}}{\text{ohms}}$, that is, $\text{Current} = \dfrac{\text{pressure}}{\text{resistance}}$.

2. $\text{Volts} = \text{amperes} \times \text{ohms}$,

   that is, $\text{Pressure} = \text{current} \times \text{resistance}$.

3. $\text{Ohms} = \dfrac{\text{volts}}{\text{amperes}}$, that is, $\text{Resistance} = \dfrac{\text{pressure}}{\text{current}}$.

CURRENT is measured by INSERTING a low resistance ammeter INTO the line.

VOLTAGE is measured by TAPPING a high resistance voltmeter ACROSS two points in the line.

RESISTANCE is measured by dividing the VOLTMETER reading by the AMMETER reading according to Ohm's law.

CAUTION. Be careful not to tap an ammeter on to a circuit as you would a voltmeter. Always BREAK the circuit and INSERT the ammeter.

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   that is, Pressure = current $\times$ resistance.

3. $\text{Ohms} = \dfrac{\text{volts}}{\text{amperes}}$, that is, $\text{Resistance} = \dfrac{\text{pressure}}{\text{current}}$.

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CAUTION. Be careful not to tap an ammeter on to a circuit as you would a voltmeter. Always BREAK the circuit and INSERT the ammeter.

PROBLEMS ON CHAPTER I

Prob. 29–1. A 30-ohm rheostat is used to control the filament current of a dry-cell type of radio vacuum tube. What is the voltage across this rheostat if the current is 0.03 ampere when all the resistance of the rheostat is in the circuit?

Prob. 30–1. In Fig. 6 the resistance of the circuit is 55 ohms. What voltage must a generator supply to the terminals AB to force 2 amperes through the lamp?

Prob. 31–1. If a car heater is supplied with a pressure of 550 volts from the trolley line, how great must be its resistance that the current may not exceed 10 amperes?

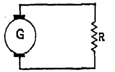

Fig. 14.

Prob. 32–1. A d-c. generator is producing a pressure of 133.5 volts at its terminals. How much current is it delivering if the resistance of the load is 63 ohms? (Connections like Fig. 14.)

Prob. 33–1. What voltage must a generator produce to supply an electroplating current of 100 amperes through a circuit whose total resistance is 0.25 ohm?

Prob. 34–1. If the generator in Fig. 14 has a terminal voltage of 35 volts, what current is flowing through the 0.85 ohm resistance?

Prob. 35–1. Suppose the generator of Fig. 14 produces 150 volts. What is the resistance of the circuit when the current is 5 amperes?

Prob. 36–1. A carbon filament lamp made to burn on a 220-volt circuit has a resistance of 520 ohms. What current does it take?

Prob. 37–1. An ammeter when used on its 10-ampere scale has a resistance of 0.019 ohm. How much current would flow through the instrument if by mistake it were used as a voltmeter on 110 volts?

Prob. 38–1. A voltmeter made to measure up to 15 volts has a resistance of 1500 ohms. How much current flows through it when used to measure 11 volts?

Prob. 39–1. A milli-ammeter gives full-scale deflection when 150 milli-amperes flow through it. This instrument can be used as a voltmeter measuring 150 volts on full-scale deflection if the proper resistance is added in series with it. What would the total resistance be under the latter condition? (A milli-ampere is 0.001 ampere.)

Prob. 40–1. In Fig. 15 the voltmeter (V) indicates 5 volts and the ammeter (A) 0.25 ampere. What is the resistance of the filament of the vacuum tube?

Prob. 41–1. The field coils of a shunt motor have a resistance of 55 ohms. What is the field current when the voltage across the coils is 232 volts?

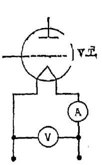

Fig. 15. Measuring the resistance of a vacuum-tube filament.

Prob. 42–1. The series field coils of a compound motor have a resistance of 0.021 ohm when carrying a current of 76 amperes. What is the voltage drop across these coils?

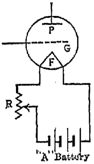

Fig. 16. The filament current of the vacuum tube is controlled by the rheostat R.

Prob. 43–1. The armature of a generator has a resistance of 0.033 ohm. What is the armature voltage drop when the generator is supplying 115 amperes?

Prob. 44–1. Which resistance is the greatest of these three: No. 1, which takes 5.19 amperes at 12 volts, No. 2, which takes 263 amperes at 550 volts, or No. 3, which takes 0.0035 ampere at 0.0015 volt?

Prob. 45–1. Fig. 16 shows a three-element vacuum tube with plate P, grid G and filament F. What size of rheostat (adjustable resistor) would you recommend to control the filament current if the tube requires 0.25 ampere and a 6-volt storage battery were to be used as "A" battery? The filament resistance is 5.2 ohms.

Prob. 46–1. Under certain conditions of contact, the resistance of the human body is about 10,000 ohms from hand to hand. What current would flow if the source of voltage were supplying 2500 volts?

Prob. 47–1. An electric baking oven takes 41 amperes at 110 volts when operated at full heat. What is its resistance under these conditions?

Prob. 48–1. An electric hotel range is to be operated on 240 volts and has a resistance of 2.4 ohms when turned fully on. What must be the current-carrying capacity of the supply feeders for this range?

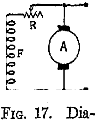

FIG. 17. Diagram showing field coils F and armature A of generator.

Prob. 49–1. In Fig. 17, R is a carbon pile resistor used to control the current in the field coils of the generator. What current will flow in these field coils when the voltage at the machine terminals is 117 volts if the combined resistance of the field coils and resistor is 37 ohms?

Prob. 50–1. The accompanying table gives data for measurements on a certain tungsten lamp. Plot a curve with volts measured horizontally and amperes vertically, thus graphically showing the relation between current and terminal voltage for this lamp. Compute the resistance for each of the voltages and plot another curve using resistance instead of current on the vertical scale. The cold resistance is 131 ohms.

Volts	Amperes
6	0.03
10	0.044
20	0.066
30	0.085
50	0.118
80	0.158
110	0.192
160	0.235
210	0.276

CHAPTER II

SIMPLE ELECTRIC CIRCUITS

13. Series Circuits and Parallel Circuits Defined. There are two ways of connecting two or more pieces of electrical apparatus.

(1) **Series.** When the pieces are connected in **tandem**, or one after the other, they are said to be in **series**. Lamps *A* and *B* of Fig. 18 are in series.

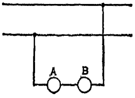

FIG. 18. Lamps *A* and *B* are in series.

(2) **Parallel.** When the pieces are connected side by side so that the current is divided between them, they are said to be in **parallel** with one another. **Multiple** or **shunt** are other names for this same combination. Lamps *C* and *D* of Fig. 19 are in parallel with each other.

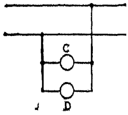

FIG. 19. Lamps *C* and *D* are in parallel.

The two combinations may exist in the same circuit, as in Fig. 20, where the parallel combination *C* and *D* is in series with the series combination *A* and *B*.

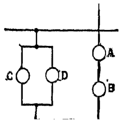

FIG. 20. Series arrangement of parallel and series combinations.

Also, as in Fig. 21, where the parallel combination *C* and *D* is in parallel with the series combination *A* and *B*.

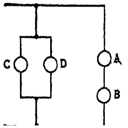

FIG. 21. Parallel arrangement of parallel and series combinations.

In this chapter only simple series and simple parallel circuits will be considered.

14. Series Circuit. Current. If we join four pipes A, B, C and D, Fig. 22, of unequal diameters together in series, and force a current of water through them, the water cannot go in at M in any greater quantity per second than it comes out at N. There must be the same current (gallons per second) flowing through each pipe no matter what its size, because no more or less can go through one than goes through all the others.

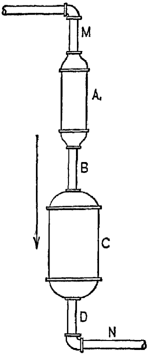

FIG. 22. No more current can flow through the large pipe C than can get through the other pipes M, A, B and D.

Similarly, we may join together in series several electrical pieces, as in Fig. 23, a resistance coil (R) of 10 ohms, an electric bell (B) of 50 ohms, and an incandescent lamp (L) of 200 ohms. Although the resistance of the coil R

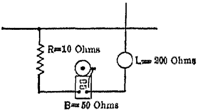

FIG. 23. Series arrangement of coil, bell and lamp. The same current flows through each.

is much lower than that of the bell or the lamp, still no greater current can flow through the coil than can get through the bell and lamp. No more electric current can enter at one end of an electric circuit than can get out at the other end, any more than can a greater current of water enter at one end of a pipe line than can go out at the other.

The first fact then to be noted is that:

In a series circuit the current is the same in all parts, no matter what the resistance may be.

15. Series Circuit. Resistance. In Fig. 24, a resistance coil R of 10 ohms is connected across the terminals of a 110-volt line. By Ohm's Law the current must equal $\frac{\text{volts}}{\text{ohms}} = \frac{110}{10} = 11$ amperes.

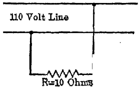

Fig. 24. A coil of 10 ohms across a 110-volt circuit.

Now suppose a lamp (L) having 45 ohms resistance is joined in series with the coil (R) across the same circuit of 110 volts as in Fig. 25. It is plain that the lamp and coil now offer a greater resistance to the current than did the coil alone. In fact, the resistance of the two pieces joined in this way is just the sum of their separate resistances, that is, $10 + 45$, or 55 ohms.

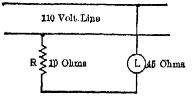

Fig. 25. Lamp and coil in series across a 110-volt circuit.

The current that flows can now be found by Ohm's Law.

$$\text{Amperes} = \frac{\text{volts}}{\text{ohms}} = \frac{110}{55} = 2 \text{ amperes.}$$

The flow of water is similarly checked by the addition of more lengths of pipe in series.

The second fact to be noted about a series circuit is that:

> **The combined resistance of pieces in series is the sum of the separate resistances.**

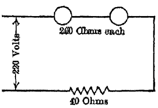

Fig. 26. The two lamps and coil are in series across a 220-volt line.

Example 1. (a) What is the resistance of the circuit in Fig. 26?

(b) What current flows in this circuit?

Resistance = 200 + 200 + 40 = 440 ohms.

$$\text{Current} = \frac{\text{volts}}{\text{ohms}} = \frac{220}{440} = 0.5 \text{ ampere.}$$

Prob. 1-2. (a) What is the total resistance of the circuit connected across the terminals of the generator in Fig. 27?

(*b*) What current flows in the circuit if the generator maintains a terminal voltage of 110 volts?

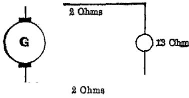

Fig. 27. A lamp in series with line wires across a generator.

Prob. 2–2. (*a*) If 10 lamps of 13 ohms each are connected in series across the generator of Prob. 1–2, what will the total resistance be?

(*b*) What will the current be under these conditions?

(*c*) Assuming the resistance to increase to 1.2 times as much as it was in (*a*) and (*b*) when the current is doubled, what voltage will be required to double the current in the 10 lamps?

Prob. 3–2. What resistance must each lamp of Fig. 28 have in order to allow a current of 6.6 amperes to flow in each? Neglect the resistance of the line wires.

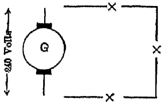

Fig. 28. Three arc lamps in series across a generator.

16. Series Circuit. Voltage. Suppose a coil (R) of 5 ohms resistance, and an arc lamp (A) of 17 ohms resistance are joined in series, as in Fig. 29, across a 110-volt line.

We have seen that the total resistance is $5 + 17 = 22$ ohms. The current flowing through the circuit is found as usual by Ohm's Law.

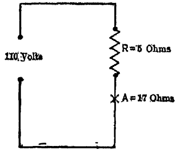

Fig. 29. A coil and arc lamp across a 110-volt line.

$$\text{Amperes} = \frac{\text{volts}}{\text{ohms}} = \frac{110}{22} = 5 \text{ amperes.}$$

Since this is a series circuit, the same current flows in each part of it. Thus there are 5 amperes flowing through the coil (R), and 5 amperes flowing through the arc lamp (A).

We are able also by Ohm's Law to find the voltage required to force the 5 amperes through the coil of 5 ohms, since volts = amperes × ohms. Thus, for the coil,

$$\begin{aligned} \text{volts} &= \text{amperes} \times \text{ohms} \\ &= 5 \times 5 = 25 \text{ volts.} \end{aligned}$$

There are required, then, 25 volts to force the 5 amperes through the 5-ohm coil.

In the same way we may find the voltage required to force the 5 amperes through the 17-ohm arc lamp. Because for the arc lamp Ohm's Law is still true, so

$$\begin{aligned} \text{volts} &= \text{amperes} \times \text{ohms} \\ &= 5 \times 17 = 85 \text{ volts.} \end{aligned}$$

There are required then 85 volts to force the current of 5 amperes through the arc lamp. We found that 25 volts are required to force the current through the 5-ohm coil.

To force the current through both, it requires 110 volts, which fact is shown by their being on a 110-volt line.

Note that the 110 volts required to force the current through the two pieces exactly equals the sum of the 25 volts across the coil R and the 85 volts across the lamp; that is, $25 + 85 = 110$ volts. It is always true in a series circuit, that if we add up the voltages across all the pieces in series, the sum will exactly equal the voltage across the series combination.

The third fact, then, to be noted about a series circuit is that:

> **The voltage across the pieces in series equals the sum of the voltages across the separate pieces.**

17. Series Circuit. Current, Resistance and Voltage. The three facts which should be learned with regard to a series circuit may be tabulated :

Series Combination

Current through series combination is	same as current through each separate part.
Resistance of series combination is	the sum of the resistances of the separate parts.
Voltage across series combination is	the sum of voltages across the separate parts.

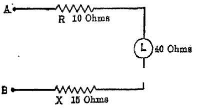

FIG. 30. The pieces R, L and X are in series.

Example 2. In the series circuit of Fig. 30, 3 amperes are flowing.

(*a*) What is the voltage across AB?

(*b*) What is the voltage across each piece?

The total resistance = 10 + 40 + 15 = 65 ohms.

Voltage to force 3 amperes through 65 ohms = 3 × 65 = 195 volts.

Answer to (*a*) then is: Voltage across AB is 195 volts.

(*b*) Volts to force 3 amperes through R (10 ohms) = 3 × 10 = 30 volts.

Volts to force 3 amperes through L (40 ohms) = 3 × 40 = 120 volts.

Volts to force 3 amperes through X (15 ohms) = 3 × 15 = 45 volts.

Volts to force 3 amperes through $R + L + X$ (65 ohms) = 195 volts.

This answer checks with the volts found in part (*a*) to be necessary to force 3 amperes through the series combination.

Prob. 4–2. (*a*) If each lamp, Fig. 31, takes 1.7 amperes, how much current must the generator deliver?

(*b*) What is the total resistance of the lamps connected across the terminals of the generator if the separate resistances are: A = 67 ohms, B = 150 ohms, C = 200 ohms?

(*c*) Under the combined conditions of (*a*) and (*b*) what is the voltage across each lamp and what is the terminal voltage of the generator?

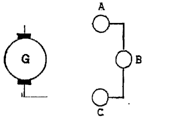

FIG. 31. Lamps in series across terminals of generator.

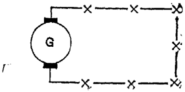

FIG. 32. Arc lamps in series across terminals of generator.

Prob. 5–2. There are seven arc lamps in series, Fig. 32, each requiring 6.6 amperes. If each has a resistance of 15 ohms when burning, how many volts must the generator supply to the line? Neglect the resistance of the line wires.

Prob. 6–2. Motor M (Fig. 33) requires a current of 50 amperes at 230 volts. The line wires have a resistance of 0.25 ohm each. What pressure must be supplied by the generator?

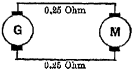

FIG. 33. Generator G and motor M in series circuit.

18. Application of Ohm's Law. It should be noted that in solving the Example on page 28, Fig. 30, Ohm's Law was used in (*a*) to find the voltage necessary to force the current through the whole circuit of the three resistances, R, L and X.

First, the total resistance was found by adding $10 + 40 + 15 = 65$ ohms.

Then, to find the total voltage necessary, we said:

(Total) voltage = (total) current × (total) resistance.
(Total) voltage = $3 \times 65 = 195$ volts.

Note that to find the **total** voltage, it was necessary to use the **total** current and **total** resistance.

But later when we wished to find the voltage necessary to force the current through the 10-ohm coil **only**, we used Ohm's Law again. But this time, since we wanted the voltage across the 10-ohm coil **only**, we used the resistance of the 10 ohms **only**, and not the total resistance of the circuit. We also had to use the current through the 10-ohm coil **only**. Thus we said:

Voltage (across 10-ohm coil) = current (through 10-ohm coil) $\times$ resistance (of 10-ohm coil) $= 3 \times 10 = 30$.

Thus to find the voltage across the **10-ohm coil**, we used the current through the **10-ohm coil**, and the resistance of the **10-ohm coil**.

Thus it can be seen that Ohm's Law may be applied either to the whole of a circuit or to any part of a circuit.

But if it is applied to the **whole** circuit, the voltage, resistance and current must be the voltage, resistance and current of the **whole** circuit, and not of merely a part. And if it is applied to a **part** of a circuit, the voltage, current and resistance must be the voltage, current and resistance of **just that part**, and no more or less.

This is of vital importance in applying Ohm's Law. Many mistakes are made in the use of this simple law, just because we fail to be careful to use the voltage, current and resistance of the **same** part of the circuit.

Note the use of this rule in the following:

Example 3. In Fig. 34 a lamp of 50 ohms, a resistance of 20 ohms, and another lamp of 30 ohms are connected in series across the points A and B. The 30-ohm lamp has a pressure of 120 volts across it.

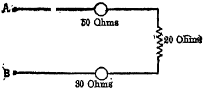

FIG. 34. Two lamps and resistor in series.

Find:

(*a*) Current through each piece.
(*b*) Voltage across each piece.
(*c*) Voltage across AB.

We are able to find the current through the 30-ohm lamp, because we know **both** the resistance and pressure.

$$\text{Current (through 30-ohm lamp)} = \frac{\text{voltage (across 30-ohm lamp)}}{\text{resistance (of 30-ohm lamp)}}$$
$$= \tfrac{120}{30} = 4 \text{ amperes.}$$

Thus the current through the 30-ohm lamp is 4 amperes. But since the 50-ohm lamp and the 20-ohm resistance are in series with the 30-ohm lamp, the same current must pass through them. Therefore, we can find the voltage across the 20-ohm coil as follows:

$$\text{Voltage (across 20-ohm coil)} = \text{current (through 20-ohm coil)} \times \text{resistance (of 20-ohm coil)}$$
$$= 4 \times 20 = 80 \text{ volts.}$$

$$\text{Voltage (across 50-ohm lamp)} = \text{current (through 50-ohm lamp)} \times \text{resistance (of 50-ohm lamp)}$$
$$= 4 \times 50 = 200 \text{ volts.}$$

Since this is a series circuit, the voltage across the whole circuit, that is, across AB, equals the sum of the voltages across the separate parts, or

$$\text{voltage across } AB = 120 + 80 + 200 = 400 \text{ volts.}$$

The answers then are

(*a*) Current through each part = 4 amperes.
(*b*) Voltage across 20-ohm coil = 80 volts.
" " 50-ohm lamp = 200 volts.
(*c*) Voltage across AB = 400 volts.

Note that after we had found the current of the **whole** circuit, we might have added up the resistances and found the resistance of the **whole** circuit, thus $30 + 20 + 50 = 100$ ohms.

Then voltage (across total circuit) = current (through total circuit) $\times$ resistance (of total circuit).

$$4 \times 100 = 400 \text{ volts.}$$

This checks with the total voltage as found by the first method.

Prob. 7-2. Lamp L, Fig. 35, requires 7 amperes. Generator terminal voltage is 220 volts. Resistance of each line wire is 2 ohms.

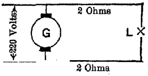

FIG. 35. Arc lamp and two line wires in series with generator.

(*a*) What is the voltage drop in the line wires?

(*b*) What is the voltage at the lamp terminals?

(*c*) What is the resistance of the lamp?

Prob. 8-2. Fig. 37 represents a potentiometer of 50,000 ohms resistance connected across a 45-volt "*C*" battery. This arrangement is used to supply a variable voltage for the grid circuit of a vacuum tube.

(*a*) What current flows through the potentiometer?

(*b*) What is the voltage across AB if the adjustable contact C is at the extreme left end?

(*c*) What is the voltage across AB if the contact C is at a point 2500 ohms from the left?

(*d*) Where would contact C have to be to give a voltage of 27 volts between A and B?

(*e*) Could 50 volts be obtained across AB with this arrangement? What is the maximum voltage available?

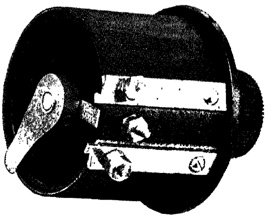

FIG. 36. Potentiometer having a maximum resistance of 50,000 ohms. General Radio Co.

Prob. 9-2. Answer the questions in Prob. 8-2 if a battery of 67.5 volts is used.

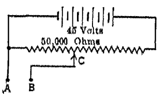

FIG. 37. Diagram of connections for potentiometer of Fig. 36 used to control "C" battery voltage.

Prob. 10-2. A dry cell has a voltage of 1.5 volts when no current is flowing. Its internal resistance is 0.05 ohm. What

current will it deliver on short circuit (that is, if the terminals are connected with a wire of almost zero resistance)?

Prob. 11–2. Old dry cells have a high internal resistance. How much current will the cell of Prob. 10–2 give on short circuit when the internal resistance becomes 2 ohms? Assume that the internal voltage remains at 1.5 volts.

Prob. 12–2. When an old dry cell delivers a current, bubbles form on the electrodes causing a still larger increase in internal resistance. What short-circuit current will the dry cell of Prob. 10–2 deliver if the internal resistance becomes 10 ohms?

Prob. 13–2. A 10-ohm resistor is connected in series with a 15-ohm resistor.

(*a*) What voltage must be placed across this combination to send a current of 5 amperes through it?

(*b*) Under the conditions of (*a*), what would be the voltage across each resistor?

(*c*) For what voltage across the combination would the voltage across the 15-ohm resistor be 60 volts?

Prob. 14–2. Six arc lamps are joined in series by wires having a total resistance of 10 ohms. (See Fig. 38.) Each lamp has a resistance of 14 ohms. How much voltage is required to send 6.6 amperes through the circuit? Assume that the seven connecting wires have equal resistances.

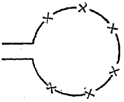

FIG. 38. Series-connected arc lamps.

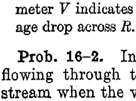

FIG. 39. Ammeter *A* indicates current in all parts of circuit; voltmeter *V* indicates voltage drop across *R*.

Prob. 15–2. (*a*) What is the voltage across each lamp in Problem 14–2?

(*b*) What is the total line drop in voltage?

(*c*) If one lamp should become short-circuited, what would the new voltage on the circuit have to be to maintain a current of 6.6 amperes?

Prob. 16–2. In an arc welder, a current of 200 amperes is flowing through the arc. What is the resistance of the arc stream when the voltage across it is 50 volts?

Prob. 17–2. Ammeter (A), Fig. 39, reads 2.4 amperes; voltmeter (V) reads 41 volts. Find:

(a) Resistance of R.
(b) Voltage across 36-ohm resistor.
(c) Voltage across 42-ohm resistor.
(d) Voltage across generator.

19. Parallel Circuit. Voltage. Suppose, as in Fig. 40, we should join two main pipes R and S by means of three parallel pipes A, B and C. All the parallel pipes lie be-

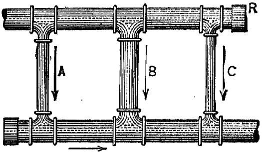

FIG. 40. Pipes A, B and C are connected in parallel.

tween the same two levels, that is, the levels of R and S. Thus there is the same difference of level across them. We have seen that it is this difference of level that causes the pressure, and tends to cause a current to flow from the higher level to the lower. In this case, the water flowing through A, B and C enters all pipes at the same high level and leaves at the same low level. Since the water is forced to flow by the pressure caused by the same difference in level, it may be seen that the pressure across each pipe is the same. In each case it is merely the pressure between R and S. If we put a thousand pipes between R and S, the pressure across them would be the pressure between R and S and, therefore, the pressure across them would be the same.

Similarly, suppose we join three electrical pieces A, B, C, Fig. 41, in parallel, between two main wires R and S. They all lie between R and S, and whatever voltage there

is across RS will be across each of the pieces A, B and C. The voltage across each will, therefore, be the same, that is, the voltage across RS, or 120 volts. Thus the voltage across A is 120 volts, the voltage across B is 120 volts and the voltage across C is 120 volts.

The first thing to be noted in a parallel circuit is that:

> **The voltage across the parallel combination is the same as the voltage across each branch.**

20. Parallel Circuit. Current. Turning again to Fig. 40, it is seen that, since the pipes A, B and C are not joined in series, they are independent of one another, and do not have to carry the same current. In fact, it is very evident that the largest pipe will carry the largest current and the smallest pipe the smallest current. Water and electricity **do not** take the path of least resistance. They take **all** paths. Where the path is of small resistance, a heavy current flows. Where there is a path of large resistance, a small current flows. But the water or the electricity is sure to make use of **both** the low resistance and the high resistance paths and force as much current as possible through both. The total current that flows through is merely the sum of the currents in the separate paths.

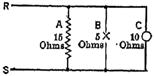

FIG. 41. Branches A, B and C are connected in parallel.

Thus, in Fig. 41, since the resistance of the branch A is high, a small current only will flow through it. By applying Ohm's Law to this branch alone, we can find this current. We have seen that the voltage across A is 120 volts. Now the resistance is 15 ohms and Ohm's Law applies as follows to find the current:

$$\text{Current (through } A) = \frac{\text{voltage (across } A)}{\text{resistance (of } A)}$$
$$= \tfrac{120}{15} = 8 \text{ amperes.}$$

Similarly, we can find the current through B.

$$\text{Current (through } B) = \frac{\text{voltage (across } B)}{\text{resistance (of } B)}$$
$$= \tfrac{120}{5} = 24 \text{ amperes,}$$

and also the

$$\text{current (through } C) = \frac{\text{voltage (across } C)}{\text{resistance (of } C)}$$
$$\tfrac{120}{10} = 12 \text{ amperes.}$$

The current then flowing between R and S by all three paths is merely the sum of these currents or $8 + 24 + 12 = 44$ amperes. This is also the current in the two main wires.

The second fact to notice in a parallel circuit is that:

> **The current flowing through the parallel combination is merely the sum of the currents in the separate branches or paths.**

Prob. 18-2. Generator G (Fig. 42) maintains a voltage of 550 volts across resistors A, B and C of 10, 65, and 500 ohms resistance respectively. What is the current in each and what is the current supplied by the generator?

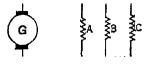

FIG. 42. The same voltage exists across each of the branches A, B and C.

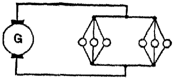

FIG. 43. The 6 lamps in parallel take 6 times as much current as 1 lamp.

Prob. 19-2. Each lamp in Fig. 43 takes 0.55 ampere. How much current is supplied by the generator?

21. Parallel Circuit. Resistance. Suppose that it is desired to find the resistance of a parallel combination, as A, B and C, in Fig. 44. There are formulas for this, but the easiest method is to apply Ohm's Law as follows:

We have seen that

The current through $A = \frac{120}{15} = 8$ amperes.
The " " $B = \frac{120}{5} = 24$ "
The " " $C = \frac{120}{10} = \underline{12}$ "
Current through combination $= 44$ amperes.

Now since we know the **current through the combination** (44 amperes) and the **voltage across the combination** (120 volts) we can find the **resistance of the combination.**

$$\textbf{Resistance (of combination)} = \frac{\text{voltage (across combination)}}{\text{current (through combination)}}$$
$$= \frac{120}{44} = 2.73 \text{ ohms.}$$

At first sight it may seem strange that the resistance of a combination of three pieces of 5, 10 and 15 ohms should be only 2.73 ohms. But the apparent difficulty disappears when we consider that the more paths we have in parallel for the current to flow from one point to another, the lower the resistance between those two points. Thus, if there had been only the 5-ohm path between the points R and S, then the resistance between these points would have been 5 ohms. But when another path of 10 ohms was run between the same points R and S, more current could flow and thus the resistance between the points became less than 5 ohms. And when a third resistance of 15 ohms was added, the resistance became still smaller. Thus we may see that the resistance of any parallel combination is less than the resistance of the path of smallest resistance. The path having the smallest resistance in this case is the 5-ohm path, and the combined resistance of the three parallel paths amounts to but 2.73 ohms.

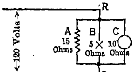

FIG. 44. Coil A, arc lamp B, and incandescent lamp C in parallel across 120 volts.

Or, referring to Fig. 40, it can be seen that the more pipes there are connected in parallel between the main pipes R and S, the easier it is for the water to get from one main pipe to the other. Hence the smaller the resistance between the main pipes.

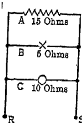

FIG. 45. The combined resistance of pieces A, B and C is 2.73 ohms.

Suppose we were given merely the three parallel resistances A, B and C, Fig. 45, and there were no mention made of any voltage across them. We could find the resistance of the parallel combination as follows:

First find the current that one volt would force through each branch.

$$
\begin{array}{lll}
\text{Current (per volt) through } A = \frac{1}{15} & = 0.0667 & \text{ampere.} \\
\text{Current} \quad `` \quad `` \quad `` \quad B = \frac{1}{5} & = 0.2 & `` \\
\text{Current} \quad `` \quad `` \quad `` \quad C = \frac{1}{10} & = 0.1 & `` \\
\text{Current through combination} = \text{sum} & = \overline{0.3667} & \text{ampere.}
\end{array}
$$

Now if one volt would force 0.3667 ampere through the combination,

$$\text{resistance (of combination)} = \frac{\text{voltage (across combination)}}{\text{current (through combination)}}$$

$$= \frac{1}{0.3667} = 2.73 \text{ ohms.}$$

This checks with the value found above.

We have used the expression "current per volt" in the above paragraph, as for instance,

current per volt through $A = \frac{1}{15}$ ampere
and current per volt through $B = \frac{1}{5}$ ampere.

Note that this value, $\frac{1}{15}$, is the reciprocal (or inverse) of the resistance of A (15 ohms), and the value $\frac{1}{5}$ is the reciprocal of 5, the resistance of B (5 ohms). This reciprocal of the

resistance is sometimes called the **conductance**. Thus, in the last example, a piece of

15 ohms resistance has $\frac{1}{15}$ **conductance.**
5 " " has $\frac{1}{5}$ "
10 " " has $\frac{1}{10}$ "

Note that the larger the resistance is, the smaller the conductance becomes. The conductance of a parallel combination is merely the sum of the conductances of the separate branches. Thus 0.3667 is the conductance of the parallel combination in the example.

Conductance, then, is merely another name for the term "amperes per volt," or "current per volt."

When the several branches of a parallel combination are of the same resistance, the problem becomes very easy.

Suppose that in Fig. 46 the resistance of each lamp is 200 ohms. Since there are 5 equal paths for the current to flow through, it must be 5 times as easy to get from A to B by 5 paths as by one path. That is, the resistance of the 5 parallel paths must be only $\frac{1}{5}$ as great as the resistance of one path. Thus the resistance of the parallel combination simply equals $\frac{200}{5} = 40$ ohms.

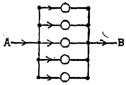

FIG. 46. The resistance between A and B is only $\frac{1}{5}$ that of one lamp.

If we had been given that the resistance of the combination was 40 ohms, and were required to find the resistance of each, it would seem rather strange to multiply the resistance of the combination (40 ohms) by 5 in order to get the resistance of one path. But this would be the correct method because the resistance of but one path must be 5 times as much as the resistance of 5 parallel paths.

The third fact to note about a parallel combination is that:

The resistance of a parallel combination is found by applying Ohm's Law. First find the current through each branch. Add

these to find the current through the combination. Then the resistance of the combination equals the voltage across the combination divided by this current through the combination. When no voltage across the combination is given, use one volt.

Example 4. Resistances of 2 ohms, 3 ohms and 4 ohms are joined in parallel. What is the resistance of the combination?

Current (per volt) through 2 ohms	$= \frac{1}{2}$	$= 0.5$	amp.
" " " " 3 ohms	$= \frac{1}{3}$	$= 0.333$	"
" " " " 4 ohms	$= \frac{1}{4}$	$= 0.25$	"
" " " " combination	= sum	$= 1.083$	amp.

$$\text{Resistance (of combination)} = \frac{\text{voltage (across combination)}}{\text{current (through combination)}}$$

$$= \frac{1}{1.083} = 0.923 \text{ ohm.}$$

The three facts which should be known about a parallel combination may be tabulated as follows:

(Compare them with the Series Table in Summary.)

Parallel Combination

Current through parallel combination equals	**sum** of currents through separate branches.
Voltage across parallel combination is	**same** as voltage across each branch.
Resistance of a parallel combination is	**less than** resistance of the branch having smallest resistance and can be found by Ohm's Law plus a little common sense.

Prob. 20–2. A parallel circuit has branches with respective resistances 1, 3, 10, 20 and 50 ohms.

(*a*) What is the conductance of each branch?
(*b*) What is the conductance of the combination?
(*c*) What is the resistance of the combination?

Prob. 21–2. Vacuum tubes are often operated in parallel across a common "A" battery. If 6 tubes, each rated at 3 volts, 0.06 ampere are to be supplied by the same "A" battery,

(*a*) What is the resistance of each filament?
(*b*) What is the resistance of the six in parallel?
(*c*) What will be the current and voltage required by the combination?

Prob. 22–2. The lamps and other appliances attached to our house-lighting circuits are usually connected in parallel. The No. 14 wire used in branch circuits can safely carry 15 amperes. How many 0.5-ampere lamps could safely be lighted at one time on one of these branches? How many of these lamps could be safely used when a 5-ampere electric toaster is operating from the same branch?

Prob. 23–2. Lamps having resistances of 121 ohms, 242 ohms, and 807 ohms are operated in parallel from the same source. If the first takes 0.91 ampere from the line, what current does each of the others take, and what is the current taken by the combination?

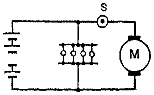

FIG. 47. Starting motor and lamps of an automobile in parallel across storage battery.

Prob. 24–2. Five identical lamps operate in parallel from the same 110-volt source taking a total of 3.55 amperes. What is the resistance of each lamp?

Prob. 25–2. When the self-starter switch *S* (Fig. 47) of an automobile is closed, it places the starting motor and the lights across the storage battery which under these conditions has a terminal voltage of 3.5 volts. The motor requires 200 amperes to turn it over and the lamps ordinarily require a total current of 10 amperes when operating normally on 6 volts. Assuming that the lamps do not change their resistance, what total current is demanded of the battery at the instant of starting? What is the internal resistance of the storage battery if its e.m.f. is 6 volts?

SUMMARY OF CHAPTER II

Electrical pieces connected in TANDEM are said to be in SERIES.

Electrical pieces connected SIDE BY SIDE are said to be in PARALLEL.

Series Combination

Current through series combination is	same as current through separate parts.
Resistance of series combination is	sum of resistances across the separate parts.
Voltage across series combination is	sum of voltages across separate parts.

Parallel Combination

Voltage across parallel combination is	same as voltage across each branch.
Current through parallel combination is	sum of currents through each branch.
Resistance of parallel combination is	less than resistance of branch of smallest resistance. It is found by using Ohm's Law plus a little common sense.

Ohm's Law applied to any electric circuit should read:

The amperes through any PART of a circuit equal the volts through that same PART of the circuit, divided by the ohms of that same PART of the circuit.

PROBLEMS ON CHAPTER II

Prob. 26–2. In Fig. 48 (parallel combination):

Resistance A = 60 ohms;
" B = 40 "
" C = 90 "
Voltage across combination = 120 volts.

Find:

(*a*) Voltage across each.
(*b*) Current through each.
(*c*) Current through combination.
(*d*) Resistance of combination.

Prob. 27–2. If each lamp of the combination, Fig. 48, were replaced by one taking 0.5 ampere, how many amperes must the generator deliver?

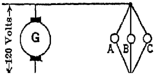

Fig. 48. Group of 3 lamps in parallel.

Prob. 28–2. In Fig. 48, suppose the lamps A, B, and C to be replaced by devices requiring currents of 6 amperes, 0.75 ampere and 2 amperes. What is the largest resistance the line wires may have to produce 110 volts at the load when 120 volts is maintained at the generator? What is the total resistance between generator terminals?

Prob. 29–2. In Prob. 26–2, what is the conductance of each lamp? What is the conductance of A and B together? What is the conductance of A, B, and C together?

Prob. 30–2. A divided circuit has three branches of 5, 10, and 20 ohms resistance respectively. What is the joint conductance of the three branches? What is the joint resistance?

Prob. 31–2. A current of 20 amperes flows in the 5-ohm branch of Prob. 30–2. Find the current in each of the other branches and the current taken by the combination.

Prob. 32–2. In Fig. 49, the two branches have resistances as follows: x is 0.20 ohm and y is 0.10 ohm. What is the conductance of each branch? What is the total conductance? What is the resistance of the combination?

FIG. 49. Resistors x and y are in parallel.

Prob. 33–2. Find the resistance of the combination of two resistors in parallel in Prob. 32–2 if they have resistances of 2.00 ohms and 1.00 ohm respectively.

Prob. 34–2. What do the answers of Prob. 32–2 become if the resistances are equal; that is, $x = y = 0.20$ ohm?

Prob. 35–2. If 12 lamps of 226 ohms each are put in parallel across 104 volts, find:

(*a*) Resistance of combination.
(*b*) Current through each lamp.
(*c*) Current through the combination.

Prob. 36–2. In Fig. 50, 7.5 amperes flow in the line, and the lamps have 104 volts across them.

Find:

(*a*) Current through each lamp.
(*b*) Resistance of each lamp.
(*c*) Voltage across each lamp.
(*d*) Resistance of the combination.

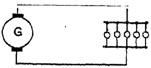

FIG. 50. The generator supplies 5 lamps in parallel.

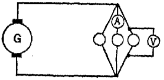

FIG. 51. Ammeter A indicates current taken by each lamp; voltmeter V indicates voltage across each lamp.

Prob. 37–2. In Fig. 51, the three lamps have practically the same resistance. Voltmeter (V) reads 100 volts. Ammeter (A) reads 0.45 ampere.

Find:

(*a*) Resistance of each lamp.
(*b*) Current in the main line.
(*c*) Voltage across each lamp.

Prob. 38–2. In Prob. 37–2, the line wires have resistances of 0.51 ohm each. What is the total resistance between the terminals of the generator and what is the voltage there?

Prob. 39–2. In Fig. 52, the ammeter reads 5.4 amperes. Each lamp has a voltage of 90 volts across it.

Find:

(*a*) Voltage across *R*.
(*b*) Resistance of *R*.
(*c*) Resistance of each lamp.

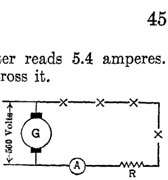

FIG. 52. Ammeter *A* indicates the current in the series circuit.

Prob. 40–2. If one lamp in Prob. 39–2, Fig. 52, becomes short-circuited, what will *R* have to be made to keep the current down to 5.4 amperes?

Prob. 41–2. If one lamp in Prob. 36–2 becomes open-circuited, what voltage must be put across the remaining four lamps in order that the current in the line may remain the same? Consider the resistance of each lamp to remain as in Prob. 36–2.

Prob. 42–2. Three resistors, one of 12 ohms, one of 21 ohms, and a third unknown are placed in parallel. The resistance of the combination is 4.65 ohms. What is the resistance of the third resistor?

Prob. 43–2. If the 12-ohm resistor of Prob. 42–2 is carrying 2.3 amperes, what is the current in each of the others and in the combination?

Prob. 44–2. What voltage is required to force a current of 10 amperes through a parallel combination of three branches having respective resistances of 15.3 ohms, 1.3 ohms, and 10.5 ohms? What will be the current in each branch?

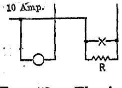

FIG. 53. The incandescent lamp is in parallel with the arc lamp and the resistor.

Prob. 45–2. Three pieces, one of 15 ohms, one of 22 ohms, and a third of 28 ohms are placed in series across a 110-volt line. It is found that a current of 1.55 amperes flows. What must be the resistance of the wires used to connect the pieces?

Prob. 46–2. What is the voltage across each piece in Prob. 45–2?

Prob. 47–2. In Fig. 53, the arc lamp has a resistance of 18 ohms, the incandescent lamp has a resistance of 84 ohms and a current of 1.32 amperes. The line carries a current of 10 amperes.

Find:

(*a*) Voltage across the parallel combination.
(*b*) Current through the resistance (R).
(*c*) Resistance of (R).
(*d*) Resistance of the combination.

Prob. 48–2. In a certain radio receiver, four vacuum tubes are operated in parallel from a set of dry cells. Three of the tubes require 0.06 ampere each and the other requires 0.12 ampere. What is the total current taken from the dry cells?

Prob. 49–2. The voltage between the trolley wire and the rails of an electric railway is 550 volts. In order to make a single 110-volt, 0.25 ampere tungsten lamp burn on this circuit, how much resistance must be placed in series with it?

Prob. 50–2. If five of the lamps mentioned in Prob. 49–2 are connected in series across the 550-volt supply, what current will flow through the combination? What will be the current through each lamp and what will be the voltage across each lamp?

Prob. 51–2. Suppose five lamps, supposedly equal but actually having hot resistances of 484, 403, 512, 475, and 475 ohms are placed in series across a 550-volt trolley-car circuit,

(*a*) What will be the current in each lamp?
(*b*) What voltage will exist across each lamp?
(*c*) What would be the visible effect of such a grouping of lamps?

Prob. 52–2. What voltage is required across a line on which there are 12 arc lamps in series, each of 8 ohms resistance, if each lamp requires 6.5 amperes to operate it? Count the line wire resistance as 10 ohms.

Prob. 53–2. How many arc lamps each having a resistance of 7 ohms and requiring a current of 6.5 amperes can be run in series on a 1000-volt line? Neglect the resistance of the line wire.

Prob. 54–2. If the line wire in Prob. 53–2 has a resistance of 12 ohms, how many arc lamps could be run in series on it as per Prob. 53–2?

Prob. 55–2. The terminals of a generator have a pressure of 110 volts. What current is flowing in a wire of 0.02 ohm connected across the terminals?

Prob. 56–2. What current will flow if an incandescent lamp of 484 ohms be connected across the generator of Prob. 55–2?

Prob. 57–2. The copper bus-bar on the back of a switchboard is carrying 500 amperes. The voltage across the ends of it is found to be 0.3 volt. What is the resistance of the bus-bar?

Prob. 58–2. The arc lamp in Fig. 54 requires 6.5 amperes at 85 volts across the arc to make it burn with a steady light. What resistance R must be added to the lamp in order to run it on a 115-volt line?

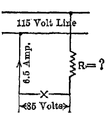

FIG. 54. Arc lamp with series resistor across 115-volt line.

Prob. 59–2. The resistance of an arc lamp is 12.3 ohms. It requires 6.5 amperes to make it burn properly. How much resistance must be added to enable it to be run on a 110-volt line?

Prob. 60–2. The resistance of a parallel circuit of two branches is 4 ohms. The resistance of one of the branches is 16 ohms. What is the resistance of the other?

Prob. 61–2. If 6 amperes are sent through the 16-ohm branch of Prob. 60–2:

(*a*) What voltage will be required?

(*b*) What current will flow in the other branch?

Prob. 62–2. The average resistance of the human body is 10,000 ohms. About 0.1 ampere through the body is usually fatal. What is the lowest voltage which would ordinarily kill a person?

Prob. 63–2. It requires 3.8 volts to force a current of 40 amperes through 5 miles of wire. What is the resistance of the wire per mile?

Prob. 64–2. What voltage would be required to force 60 amperes through 8 miles of the wire in Prob. 63–2?

Prob. 65–2. How much resistance must be placed in series with a coil on a 110-volt line in order to reduce the current from 2.18 amperes to 1.54 amperes?

Prob. 66–2. (*a*) What is the voltage across AD, Fig. 55? (*b*) What is the voltage across AB?

Prob. 67–2. What voltage would be required to send 8 amperes through the line in Prob. 66–2?

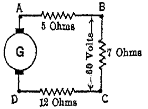

FIG. 55. The generator voltage is divided among the 3 resistors.

Prob. 68–2. What would be the combined resistance of the three wires in Fig. 55, if they were joined in parallel?

Prob. 69–2. What voltage would be required to send 8 amperes through the resistances joined as in Prob. 68–2?

Prob. 70–2. What would be the current through each resistance in Prob. 69–2?

CHAPTER III

COMBINATIONS OF SERIES AND PARALLEL SYSTEMS

22. Parallel Lighting Systems. Modern incandescent lamps are usually installed in parallel. The resistance of all the lamps, even of the same make, is not the same. Nor is the voltage across all the lamps when installed the same. Still, for convenience in calculating the "line drop in voltage," that is, the voltage necessary to send current through the line, each lamp is assumed to take the same current. The error introduced by this assumption is usually too small to be taken into account.

In practice, it is seldom that we find a simple series circuit, or a simple parallel circuit. The two arrangements are usually combined into a more or less complicated system. But by considering each part of the circuit by itself and applying Ohm's Law to each part separately, it is easy to find the current, voltage and resistance distribution throughout the entire circuit of any system. The same rules that we have learned apply, and apply in the same way. A little practice is all that is needed in order to solve the most difficult of such arrangements.

For instance, consider the following:

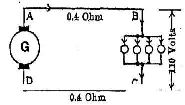

FIG. 56. Voltage at generator must be higher than at lamps on account of voltage drop in line.

Example 1. In a lighting system, as shown in Fig. 56, each lamp takes $\frac{1}{2}$ ampere at 110 volts. We wish to find the voltage which the generator must deliver in order to force the current through the line wires and still have 110 volts left to force the current through the lamps.

The parallel combination of four lamps BC is really in series with the two line wires AB and CD.

First, we find the current distribution throughout the whole circuit and mark it upon the diagram as in Fig. 57.

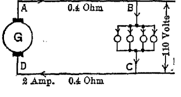

FIG. 57. The current in the line wires is the sum of the currents in the lamps.

We start with the parallel combination of lamps. As the lamps are in parallel, the current through the combination BC must be the sum of the currents in the four branches. Thus the current from B to C must be 4×0.5 ampere or 2 amperes.

Now, since the line wire AB is in series with the combination BC, the same current must flow through the line wire AB as flows through the parallel combination BC. Thus the 2 amperes must flow through the line wire AB.

The line wire CD is also in series with the parallel combination BC, so the same current (2 amperes) must flow through CD.

We now have the current distribution throughout the entire circuit. We can then find the voltage distribution in the same way. First find the voltage necessary to force the current through the line. We must force 2 amperes through a line wire AB, of 0.4 ohm resistance in order to get it to flow through the lamps.

To force 2 amperes through 0.4 ohm requires $0.4 \times 2 = 0.8$ volt. (Volts = ohms $\times$ amperes.) Thus it requires 0.8 volt to get the current out to the lamps.

Similarly, it requires 0.8 volt to get the current back from the lamps to the generator through the line wire CD, since we must force the same 2 amperes through the 0.4-ohm resistance of this wire. The voltage is then distributed as in Fig. 58.

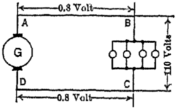

FIG. 58. The line drop is 0.8 volt per wire.

Thus we have the voltages across the three parts of the circuit which are in series. The voltage across the whole series system, then, is the sum of the voltages across the separate parts.

Voltage across	AB	=	0.8 volt
" "	lamp	=	110.0 "
" "	CD	=	0.8 "
" "	combination	=	111.6 volts.

The 1.6 volts used to send the current through the line wires is said to be the "volts lost in the line," or "line drop."

Therefore the generator must impress 111.6 volts on the system in order to use 0.8 volt forcing the current through the section of line out to the lamps, and 0.8 volt forcing it through the return section, and still have 110 volts left for the lamps.

The general method of attack for this type of problem may then be summarized as follows:

First. Find the current distribution throughout the circuit.

Second. Find the voltage distribution throughout the circuit.

Third. Combine the voltages according to the rules for a series circuit.

Prob. 1–3. The generator in Fig. 59 delivers a pressure of 110 volts.

(*a*) If each lamp takes 1 ampere, what will be the voltage across the lamps?

(*b*) What will be the line drop?

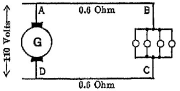

FIG. 59. Voltage across lamps is less than 110 volts.

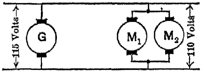

FIG. 60. Motors M_1 and M_2 are in parallel.

Prob. 2–3. In Fig. 60, M_1 takes 25 amperes, M_2 takes 30 amperes. How much resistance can each line wire have in order that the voltage of the generator may be 115 volts, and 110 volts may be supplied at the motors?

Prob. 3–3. In Fig. 61, ammeter I reads 60 amperes; ammeter II reads 25 amperes. How much current does M_2 take? If the motors require 110 volts, what must the generator voltage be? The line wires have a resistance of 0.15 ohm each.

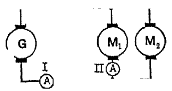

FIG. 61. Ammeter I reads currents supplied by generator; ammeter II reads current taken by motor M_1.

Prob. 4–3. Each of the vacuum tubes A and B, Fig. 62, requires 0.06 ampere at 3 volts and tube C requires 0.25 ampere at 5 volts. What are the resistances of the smallest rheostats that can be used to control the currents if a 6-volt " A " battery is used?

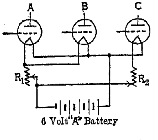

FIG. 62. Filament currents of tubes A and B are controlled by rheostat R_1; that of tube C by R_2.

Prob. 5–3. A pressure of 110 volts is maintained at the distribution panel of an apartment house. One of the branches has a total resistance of 0.3 ohm. How much will the voltage at the end of the branch drop when a 6-ampere electric iron and a 5-ampere electric heater are turned on together?

23. More Complicated Grouping.

In the above examples, it will be noted that all parts of the line wires carry the same current. Systems are usually arranged so that the several sections of the line wires carry different currents, the section nearest the generator carrying more than the sections further away.

Suppose, as in Fig. 63, two lamps A and B are connected to a circuit in such a way that A, taking 3 amperes, is much nearer the generator than B, which takes 2 amperes. Then in the section of the line which lies between A and B, 2 amperes must flow in order to supply lamp B with 2 amperes. But the section of the line between the generator and A must carry enough current to supply both lamp A and lamp B. Thus this section must carry 5 amperes.

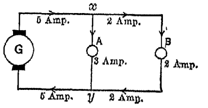

FIG. 63. The line current between the generator and lamp A is 5 amperes while the line current between the lamps is only 2 amperes.

When this current of 5 amperes in the line reaches the point x it divides, 3 amperes going down through the lamp A and the rest (2 amperes) going on through the other section to

supply the lamp B. Similarly, at the point y the two currents join, the 3 amperes coming from lamp A joining the 2 coming along the furthur section of the line from lamp B, and their combined current of 5 amperes is carried by the section of line wire between A and the generator.

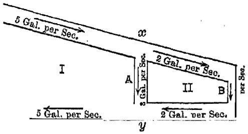

FIG. 64. Section I must carry 5 gal. per sec. in order to supply both pipes A and B; Section II carries only 2 gal. per sec.

The above electrical circuit is similar to the water pipe circuit of Fig. 64. The two pipes A, carrying 3 gal. per sec. and B, carrying 2 gal. per. sec. Section I of the pipe line must carry 5 gal. per sec. in order to supply both pipes A and B. Section II, supplying B only, has to carry but 2 gal. per sec. At point x the current of 5 gal. per sec. divides, and 3 gal. per sec. flow through A and 2 gal. per sec. go on through Section II to supply pipe B. At y the 2 gal. per sec. from Section II join the 3 gal. per sec. from pipe A, and together they pour a current of 5 gal. per sec. through the lower pipe of Section I.

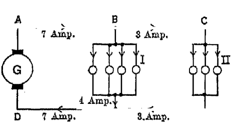

FIG. 65. Two groups of lamps at different distances from generator.

In Fig. 65, the sections AB and DE of the line are nearest the generator and thus have to carry enough current to supply both groups of lamps. Since Group I takes 4 amperes and Group II takes 3 amperes the generator must supply 7 amperes, and sections AB and DE of the line must carry 7 amperes.

Sections BC and EF, however, feed Group II only, and

thus carry only enough current to supply these lamps, namely 3 amperes.

It is very often convenient to regard the current distribution as follows:

Begin with the lamps farthest from generator. Group II requires 3 amperes, therefore, sections *BC* and *EF* must carry 3 amperes.

Group I requires 4 amperes. The part of the line *AB*, therefore, must bring enough current to the point *B*, so that 3 amperes can be sent out along *BC* to Group II and 4 amperes can be sent down through Group I to the point *E*. Thus *AB* must carry 4 + 3, or 7 amperes.

Similarly, at *E*, the 4 amperes from Group I and the 3 amperes from *EF* pour into the line *DE* and thus *DE* also must carry 7 amperes.

Prob. 6-3. If each lamp, Fig. 66, takes 0.3 ampere, how much current flows in the following sections of the line: *AB*, *BC*, *DE* and *EF*?

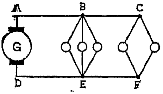

FIG. 66. The current is different in different sections of the line.

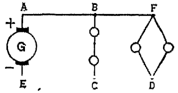

FIG. 67. Series and parallel groups of lamps supplied by generator.

Prob. 7-3. In Fig. 67, each lamp takes 0.25 ampere. How much current flows through *AB*, *BF*, *EC* and *CD*?

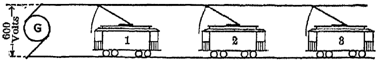

FIG. 68. Trolley cars at different distances from station.

Prob. 8-3. In Fig. 68:

Car 1 takes 50 amperes.
" 2 " 60 "
" 3 " 70 "

How much current flows in the trolley wire between:

(a) Cars 2 and 3?
(b) Cars 1 and 2?
(c) Generator and car 1?

24. Voltage Required for the Line. Line Drop. Let us assume that a circuit, Fig. 69, is arranged as in Fig. 63, except that the resistance of the line wires and the generator voltage are introduced. The wires from the generator G to the lamp A each have a resistance of 0.3 ohm. The wires from the lamp A to the lamp B each have a resistance of 0.4 ohm.

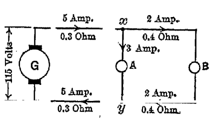

FIG. 69. The voltages across the lamps are different.

First Step. Current Distribution. As we saw in Fig. 63 each of the wires from G to A has a current of 5 amperes flowing through it, and each of the wires from A to B has a current of 2 amperes.

Second Step. Voltage Required for the Line. Line Drop. We have seen that it requires a voltage to force a current through a wire. Thus, to force the current of 5 amperes out from the generator along a 0.3-ohm wire to the point x would require

$$5 \times 0.3, \text{ or } 1.5 \text{ volts (volts = amperes} \times \text{ohms).}$$

And to force a current of 5 amperes back from y to the generator through a 0.3-ohm line wire requires

$$5 \times 0.3, \text{ or } 1.5 \text{ volts.}$$

Thus, just to force the current along the section of the line out to the lamp A and back again requires 1.5 + 1.5, or 3 volts.

Third Step. Voltage across the Lamps. If we assume that the generator furnishes a voltage of 115 volts, and that 3 volts

are used in forcing the current through the first section of the line, then all that remains for the lamp A is

$$115 - 3, \text{ or } 112 \text{ volts.}$$

A voltmeter placed across the generator would read 115 volts, but a voltmeter placed across lamp A would read only 112 volts. The 3 volts used in forcing the current through the line are said to be lost in the line, and are called the "line drop."

In the same way, to force the 2 amperes through the 0.4-ohm line out to lamp B requires 2×0.4, or 0.8 volt. And to force this 2-ampere current back from lamp B to point y through the 0.4-ohm line wire requires 2×0.4, or 0.8 volt. So to force the current from x to lamp B and back again to y requires $0.8 + 0.8$, or 1.6 volts.

Since we have only 112 volts across x and y (that is, across lamp A), if we use 1.6 volts just to force the current out to lamp B and back again, we have left but

$$112 - 1.6, \text{ or } 110.4 \text{ volts,}$$

to force the current through lamp B.

If we should put a voltmeter across lamp B, then, it would read only 110.4 volts.

Another way of looking at this problem is to draw a diagram somewhat as in Fig. 70. This shows very clearly that there are two paths between the points x and y. One path is directly through the lamp A. The other is through the 0.4-ohm line wires and lamp B. Therefore, the lamp A is in parallel with the series combination of lamp B and the 0.4-ohm line wires, since both are connected across the points x and y. So after we have found that the voltage across x and y is $115 - 3$, or 112 volts, then we know that the voltage across each of the two parallel cir-

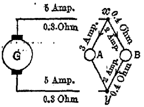

FIG. 70. Another way of drawing diagram of Fig. 69.

cuits is the same. Therefore, the voltage across lamp A is 112 volts, and the voltage across the series combination of the two 0.4-ohm wires and lamp B is 112 volts.

But we have seen that it required 1.6 volt to force the current through the two 0.4-ohm wires. Since there were 112 volts across the series combination of lamp B and line wires, if it requires 1.6 volt for line wires alone, there are left for lamp B, $112 - 1.6$, or 110.4 volts.

25. Generator Voltage. It is sometimes required to find what the voltage across the generator must be, in order to produce a given voltage across a set of lamps at a distance from the generator. This is merely a variation of the preceding example and is solved by the same method, as may be seen from the following.

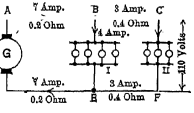

FIG. 71. Voltage at Group II must be 110 volts.

Figs. 65 and 71 are identical except that in Fig. 71 the resistance of the line wire is known and the voltage across Group II is given as 110 volts. It is required to find the voltage across the generator and Group I.

First Step. Current Distribution. Note that as each lamp takes 1 ampere, the current distribution in Fig. 71 is the same as in Fig. 65. That is, between Groups I and II, the line carries 3 amperes. Between the generator and Group I, the line carries 7 amperes. It is also essential to note that in all problems of this type we have **started by finding the current distribution.**

Second Step. Line Drop. In the section between Groups I and II, the 0.4-ohm line wire BC carries 3 amperes. It must require 3×0.4, or 1.2 volt to force this current through this wire. Similarly, it requires 3×0.4, or 1.2 volt to force the current through EF. Thus the "line drop" between Groups I and II must be $1.2 + 1.2 = 2.4$ volts.

Third Step. If there are 110 volts across Group II after the 2.4 volts have been lost in the line wires from Group I to Group II, there must be 110 + 2.4, or 112.4 volts across Group I.

Or, stating it another way:

Line wire *BC*, Group II and line wire *FE* are in series. Therefore, the voltage across the combination, that is, *B* to *E*, must be the sum of the voltages across the separate parts.

Voltage across	BC =	1.2 volts.
" "	Group II =	110.0 "
" "	FE =	1.2 "
Voltage across BE (sum)	=	112.4 volts.

But since Group I of lamps is also across the points *B* and *E*, the voltage across Group I must also be 112.4 volts.

Similarly, the voltage used up in forcing 7 amperes through the 0.2 ohm of wire $AB = 7 \times 0.2 = 1.4$ volt. And the voltage used in forcing the 7 amperes through the 0.2 ohm of the wire $ED = 7 \times 0.2 = 1.4$ volt.

Voltage across Generator (AD) = (voltage across AB) + (voltage across BE) + (voltage across ED).

Voltage across	AB =	1.4 volts.
" "	BE =	112.4 "
" "	ED =	1.4 "
Voltage across the Generator (AD)	=	115.2 volts.

Thus, the voltage across the Generator	=	115.2 volts.
" " " Group I	=	112.4 "
" " " Group II	=	110.0 "

The method in all the above is the same.

First Step. Mark the current distribution on the diagram beginning at the section farthest from the generator.

Second Step. Compute the line drop in the different sections of the line by Ohm's Law.

SUMMARY OF CHAPTER III

Combinations of series and parallel arrangements can be separated into small parts and Ohm's Law applied to each part in order to find the current, voltage and resistance distribution.

METHOD. (First step.) Find the current distribution beginning at the point farthest from the generator.

(Second step.) Compute, by means of Ohm's Law, the line drop.

(Third step.) Combine line drop with known voltages, according to the rules for series and parallel circuits.

PROBLEMS ON CHAPTER III

Prob. 13-3. In Fig. 67 each lamp takes 1.5 ampere.

Voltage of generator = 125 volts.
Resistance $AB = EC = 0.8$ ohm.
" $BF = CD = 0.7$ ohm.

Find:

(*a*) Current through each section of the line.
(*b*) Line drop in each section of the line.

Prob. 14-3. Find the voltage across *BC* and *FD*, in Prob. 13-3.

Prob. 15-3. If the two lamps which are across *BC* in Prob. 13-3 are of the same resistance, how great is the resistance of each?

Prob. 16-3. What is the resistance of each lamp across *FD* in Prob. 13-3?

Prob. 17-3. Assume the voltage across the generator in Fig. 68 to be 600 volts.

Resistance of trolley between generator and car I = 0.5 ohm.
" " " " car I " car II = 1.2 "
" " " " car II " car III = 0.4 "

SUMMARY OF CHAPTER III

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Prob. 17–3. Assume the voltage across the generator in Fig. 68 to be 600 volts.

Resistance of trolley between	generator	and car I	= 0.5 ohm.
" " " "	car I	" car II	= 1.2 "
" " " "	car II	" car III	= 0.4 "

Resistance of track between generator and car I = 0.05 ohm.
" " " " car I " car II = 0.1 "
" " " " car II " car III = 0.04 "

Car 1 takes 50 amperes.
" 2 " 60 "
" 3 " 70 "

Find:

(*a*) Voltage drop in each section of the trolley wire.
(*b*) Voltage drop in each section of the track.
(*c*) Voltage across each car.

Prob. 18–3. Assume the voltage of the generator in Fig. 68 as unknown but that the voltage across car II is 550 volts. Other data as in Prob. 17–3.

Find:

(*a*) Voltage drop in each section of the trolley wire.
(*b*) Voltage drop in each section of the track.
(*c*) Voltage across generator and each car.

Prob. 19–3. In Fig. 73, each lamp takes 1.4 ampere.

Find:

(*a*) The amount and direction of the current in the following sections of the line: FT, ET, BC, AB.

(*b*) The voltage drop in each of the above sections of line.

Prob. 20–3. Find the voltage across each lamp of Fig. 73, if the generator voltage is 125 volts, and each lamp takes 1.4 ampere.

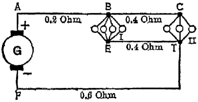

FIG. 73. Note that voltages at lamps are nearly equal due to this unusual arrangement.

Prob. 21–3. Find the voltage across the generator and Group I in Fig. 73 if the voltage across Group II is 112 volts and each lamp takes 1.4 ampere.

Prob. 22–3. Each lamp in Fig. 74 takes 1.5 amperes. Voltage across the switch = 115 volts. Resistance of each section of wire between the lamps, and from the switch to the lamps, is 0.2 ohm.

Find:

(*a*) The amount and direction of the current flowing in each section of the wire.

(*b*) Voltage drop in each section of wire.
(*c*) Voltage across each lamp.

Prob. 23-3. If the wiring of Prob. 22-3 were arranged as in Fig. 75, and all the data were the same as in Prob. 22-3.

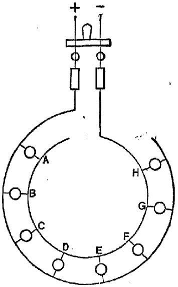

FIG. 74.

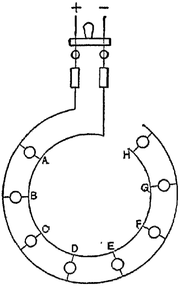

FIG. 75.

Which is the better way to connect the lamps?

Find:
(*a*) Amount and direction of the current in each section.
(*b*) Volts drop in each section.
(*c*) Voltage across each lamp.
(*d*) Which is the better method of making connections: this, or that of Prob. 22-3?

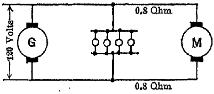

FIG. 76. Voltage at generator is maintained at 120 volts.

Prob. 24-3. In Fig. 76, each lamp takes 2 amperes. The motor takes 10 amperes. The voltage across the lamps must be 112 volts.

Find:
(*a*) The volts drop in the line between the lamps and motor.
(*b*) The voltage across the motor.
(*c*) The resistance of the line between the generator and lamps.
(*d*) The average resistance of the lamps.

Prob. 25–3. In Fig. 76, assume the resistance of the line wires from the generator to the lamps to be 0.26 ohm each, and the voltage across the lamps to be unknown. What will be the voltage across the motor when the lamps are not running?

Prob. 26–3. What will be the voltage across the lamps in Prob. 25–3 when the motor is not running?

Prob. 27–3. What will be the voltage across the lamps when the motor in Prob. 25–3 is running?

Prob. 28–3. What will be the voltage across the motor and lamps in Prob. 25–3, if the motor and lamps interchange places on the line?

Prob. 29–3. The voltage at a generator station is 120 volts. With a load of 200 amperes, the voltage at the consumer's end of the line is 116 volts. What is the line resistance?

Prob. 30–3. On the consumer's end of the line in Prob. 29–3, is a motor. When the motor is started alone on the line, the voltage at the motor drops to 112 volts. When the motor gets up speed, the voltage across it remains steady at 115 volts.

(*a*) What current does the motor take on starting?
(*b*) What current does the motor take when running?

Prob. 31–3. Four vacuum tubes in a radio receiving set have their filaments supplied from the same 6-volt "A" battery as shown in Fig. 77. Each of the tubes *A* and *B* takes 0.06 ampere at 3 volts, and *C* and *D* take 0.25 ampere each at 5 volts. What are:

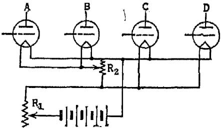

FIG. 77. Two rheostats are used to control the filament currents of two different kinds of vacuum tubes.

(*a*) The resistances of the two rheostats shown?
(*b*) The total current taken from the battery?
(*c*) The voltage drops across the rheostats?

Prob. 32–3. If the tube *C*, Prob. 31–3, should burn out what would the rheostat resistances be after adjustment to give each tube its proper voltage?

Prob. 33-3. If tube *B*, Prob. 31-3 should burn out, what would the rheostat resistances be after adjustment to give each tube its proper voltage?

Prob. 34-3. An 8-tube radio receiving set has 7 tubes with filament ratings of 0.25 ampere at 5 volts, and 1 tube with filament rating of 1 ampere at 5 volts. These are all controlled from the same rheostat and operate from an 8-volt source.

(*a*) What is the hot resistance of each filament?

(*b*) What is the resistance of the controlling rheostat when all tubes are on?

(*c*) What is the total current taken from the battery when all tubes are on?

Prob. 35-3. If one of the 0.25-ampere tubes of Prob. 34-3 should burn out, what voltages would be impressed on the remaining tubes with the same rheostat setting, assuming that the filament resistances are not changed?

Prob. 36-3. If the 1-ampere tube of Prob. 34-3 should burn out, what voltage would be impressed on the remaining tubes, assuming that the filament resistances are not changed? What will the filament currents be?

Prob. 37-3. Work Prob. 34-3 with a 6-volt rather than an 8-volt battery.

Prob. 38-3. Work Prob. 35-3 with a 6-volt rather than an 8-volt battery.

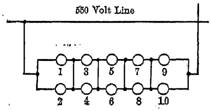

FIG. 78. A possible arrangement of lamps in a trolley car.

Prob. 39-3. Work Prob. 36-3 with a 6-volt rather than an 8-volt battery.

Prob. 40-3. Suppose lamps 1, 3, 5, 7, and 9, Fig. 78, are the lamps of Prob. 51-2 in the order listed respectively, and that each of the lamps 2, 4, 6, 8, and 10 has a hot resistance of 484 ohms.

(*a*) What will be the voltage across each lamp?

(*b*) What will be the current through each lamp?

(*c*) Compare these results with those of Prob. 51-2.

Prob. 41-3. (*a*) If one of the lamps arranged as in Prob. 51-2 burns out, what happens to the others? (*b*) If lamp No. 4,

Fig. 78 burns out, find the currents and voltages associated with each of the remaining lamps.

Prob. 42–3. If lamps 4, 6, and 8, Fig. 78, burn out, find the currents and voltages associated with each of the remaining lamps.

Prob. 43–3. A certain carbon-pile adjustable resistor, sometimes used where a smooth control of field current is desired in a motor or generator, has a minimum setting of 14 ohms and a maximum of 50 ohms. What ranges of resistance can be covered by using two of these units in series or in parallel?

Prob. 44–3. What ranges of resistance can be covered with series and parallel combinations of the resistors described in Prob. 43–3 if three of these units are available?

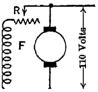

FIG. 79. Diagram showing use of rheostat to control field current of a generator or a motor.

Prob. 45–3. In adjusting the speed of a certain motor, Fig. 79, it becomes necessary to vary the resistance of rheostat R from 23 ohms to 70 ohms continuously without breaking the field circuit. What arrangement of the three resistors of Prob. 44–3 would you use if this is possible?

Prob. 46–3. If the field coils F of the motor of Prob. 45–3 have a resistance of 75 ohms, between what limits can the field current be adjusted with the arrangement of that problem if the supply is maintained at 110 volts?

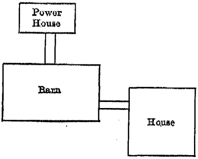

FIG. 80. Layout of farm-lighting system.

Prob. 47–3. Fig. 80 shows the layout of a 32-volt farm-lighting equipment. The feeders from the power-house to the barn have a total resistance of 0.05 ohm and from the barn to the house 0.02 ohm. When the gasoline engine in the power-house is running, the voltage sometimes rises to 35 volts. When the load is carried entirely by the storage battery, the station voltage sometimes falls to 30 volts. The largest load taken in the barn at any

one time is 105 amperes and in the house 15 amperes. Between what limits may the voltage at the house vary?

Prob. 48-3. The data below give voltages and corresponding currents for a certain carbon-filament lamp. Plot a curve with volts measured horizontally and amperes vertically, thus graphically showing the relation between these quantities for this lamp. Compute the resistance for each voltage and plot a curve using resistance instead of current on the vertical scale. The cold resistance is 342 ohms.

Volts	Amperes
9	0.030
20	0.080
30	0.134
50	0.250
70	0.367
90	0.490
110	0.609
125	0.700

Prob. 49-3. If each of the three lamps in Fig. 81 is a carbon lamp like the one of Prob. 48-3, what current will be drawn from the generator?

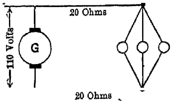

Fig. 81. Group of 3 lamps supplied by generator.

Prob. 50-3. If each of the three lamps of Fig. 81 is a tungsten lamp like the one in Prob. 50-1, what current will be drawn from the generator?

Prob. 51-3. If one of the lamps in Fig. 81 is a carbon lamp like the one of Prob. 48-3 and the other two are tungsten lamps like those of Prob. 50-1, what current will be taken from the generator and what will be the voltage at the lamps?

Prob. 52-3. (*a*) What will be the cold resistance of the combination of three lamps of Prob. 49-3?

(*b*) What will be the hot resistance of this same combination when operating with 110 volts at the lamps?

Prob. 53-3. (*a*) What will be the cold resistance of the combination of three lamps of Prob. 50-3?

CHAPTER IV

ELECTRIC POWER

26. Unit of Power. Watt. Incandescent lamps are rated as to the voltage of the line on which they can run, and also as to the amount of electric power it takes to keep them glowing. Thus, a carbon filament lamp may be rated as a 110-volt, 50-watt lamp. A tungsten lamp may be rated as a 110-volt, 25-watt lamp. This means that both lamps are intended to run on a 110-volt circuit, but that it takes twice as much power to keep the carbon filament lamp glowing as it does to keep the tungsten lamp glowing.

The flow of an electric current has been likened to the flow of water through a pipe. A current of water is measured by the number of gallons, or pounds, flowing per minute; a current of electricity, by the number of amperes, or coulombs per second. The power required to keep a current of water flowing is the product of the current in **pounds per minute** by the head, or pressure, in **feet.** This gives the power in **foot pounds per minute.** To reduce to horse power, it is necessary merely to divide by 33,000, i.e.,

$$\frac{(\text{lb. per min.}) \times (\text{feet})}{33{,}000} = \text{horse power.}$$

In exactly the same way, the **power** required to keep a current of electricity flowing is the product of the current in **amperes** by the pressure in **volts.** This gives the power in **watts.**

$$\textbf{Watts} = \textbf{amperes} \times \textbf{volts.}$$

The term **watt** is merely a unit of power, and denotes the power used when one volt causes one ampere of current

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In exactly the same way, the **power** required to keep a current of electricity flowing is the product of the current in **amperes** by the pressure in **volts.** This gives the power in **watts.**

$$\textbf{Watts} = \textbf{amperes} \times \textbf{volts.}$$

The term **watt** is merely a unit of power, and denotes the power used when one volt causes one ampere of current

to flow. The watts consumed when any given current flows under any pressure can always be found by multiplying the current in amperes by the pressure in volts. Thus, if an incandescent lamp takes 0.5 ampere when burning on a 110-volt line, the power consumed equals

$$0.5 \times 110 = 55 \text{ watts.}$$

That is,

$$\text{power} = \text{current} \times \text{pressure},$$

or

$$\text{watts} = \text{amperes} \times \text{volts}.$$

Example 1. What power is consumed by a motor which runs on a 220-volt circuit, if it takes 4 amperes?

$$\begin{aligned}\text{Watts} &= \text{amperes} \times \text{volts}\\ &= 4 \times 220.\\ \text{Power} &= 880 \text{ watts.}\end{aligned}$$

Prob. 1–4. A 20-candle-power tungsten lamp takes 0.218 ampere when on a 110-volt line. What is its rating in power consumed?

Prob. 2–4. How many watts are used in the lamp in Prob. 1–4 to produce each candle power?

Prob. 3–4. A magnetite arc lamp takes 4 amperes at 110 volts. What power is consumed?

Prob. 4–4. How much power is taken by 7 incandescent lamps if each is rated as a 40-watt lamp?

Prob. 5–4. What would be the power rating of a 32-candle-power Gem incandescent lamp, which used 2.5 watts per candle power?

27. Current Taken by Lamps. Just as Ohm's Law is used in its three forms, so the power equation is also used in three forms.

If

$$\text{watts} = \text{amperes} \times \text{volts},$$

then

$$\text{amperes} = \frac{\text{watts}}{\text{volts}}.$$

Example 2. What current will a 25-watt lamp take when burning on a 110-volt line?

$$\text{Watts} = \text{amperes} \times \text{volts},$$

or

$$\text{amperes} = \frac{\text{watts}}{\text{volts}}$$

$$= \tfrac{25}{110} = 0.227 \text{ ampere.}$$

Prob. 6–4. What current does a motor take which uses 17,000 watts on a 110-volt line?

Prob. 7–4. An arc lamp is rated at 1056 watts on a 110-volt line. What current does it take?

Prob. 8–4. What current does a 20-candle-power tungsten lamp take on a 112-volt circuit, if it requires 1.20 watt per candle power?

28. Voltage Required by Lamps. The power equation appears in a third form. This form is used when it is desired to find the voltage which will produce a given amount of power using a given current.

For if

$$\text{watts} = \text{amperes} \times \text{volts},$$

then

$$\textbf{volts} = \frac{\textbf{watts}}{\textbf{amperes}}.$$

Example 3. On what voltage must a 40-watt lamp be used if it is to take a current of 0.357 ampere?

$$\text{Volts} = \frac{\text{watts}}{\text{amperes}}$$

$$= \frac{40}{0.357} = 112 \text{ volts.}$$

Prob. 9–4. A motor is rated to take 5 amperes and to consume 1500 watts. For what voltage is it built?

Prob. 10–4. If the motor of Prob. 9–4 took 10 amperes, but consumed the same power, for what voltage would it be built?

Prob. 11–4. A 50-candle-power tantalum lamp, rated as 2.0 watts per candle power, is to take 0.45 ampere. On what voltage should it be run?

29. Three Forms of Power Equation. The power equation, then, has these three forms:

To find power,

$$(1) \qquad \text{watts} = \text{amperes} \times \text{volts}.$$

To find current,

$$(2) \quad \text{amperes} = \frac{\text{watts}}{\text{volts}}.$$

To find voltage,

$$(3) \qquad \text{volts} = \frac{\text{watts}}{\text{amperes}}.$$

Prob. 12–4. How many watts are consumed by the electric iron in Fig. 83 which uses 6.3 amperes in a 110-volt circuit?

Prob. 13–4. How much power is consumed by the group of lamps in Fig. 56 if each lamp takes 0.5 ampere?

Prob. 14–4. If motor M_1, Prob. 2–3, consumes 2550 watts, what is the voltage across it?

Prob. 15–4. A trolley car has a voltage of 550 volts and uses 21,000 watts. What current does it take?

Prob. 16–4. What current does a 60-candle-power, 115-volt tungsten lamp take if it uses 1.25 watt per candle power?

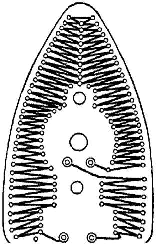

FIG. 83. Interior view of laundry iron showing heating element.

30. Measurement of Power in an Electric Circuit. If we wish to know the power that is being consumed in a certain part of an electric circuit, we merely have to insert an ammeter to measure the current in that part of the circuit, apply a voltmeter to measure the voltage across that part of the circuit, and multiply the ammeter reading by the voltmeter reading. This gives us the power directly in watts. The computation is thus merely an application of the general method which we have already expressed in the equation:

$$\text{Watts} = \text{volts} \times \text{amperes}.$$

The same precautions must be observed in the use of this equation as in the use of Ohm's Law. That is, the voltage and the current must be measured for the **same part** of the circuit at the same time; their product is the power consumed in **that part** of the circuit alone. The following example illustrates the use of the equation.

Example 4. A generator G, Fig. 84, is furnishing a current of 4 amperes to the line at a pressure of 120 volts. There is in the circuit a resistance R, which requires 5 volts to force the current through it, and a motor M, which requires 115 volts. How much power does the resistance R consume, and how much does the motor M consume?

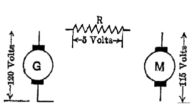

FIG. 84. Motor and resistor in series with generator.

The resistance R consumes:

$$\text{Watts} = \text{amperes} \times \text{volts}.$$

That is,

$$\text{watts (in } R) = \text{amperes (through } R) \times \text{volts (across } R).$$
$$4 \times 5 = 20 \text{ watts.}$$

The motor consumes:

$$\text{Watts} = \text{amperes} \times \text{volts}.$$

That is,

$$\text{watts (in } M) = \text{amperes (through } M) \times \text{volts (across } M)$$
$$= 4 \times 115 = 460 \text{ watts.}$$

The power consumed by R and the motor together

$$= 20 + 460 = 480 \text{ watts,}$$

or, combining the above into one equation,

$$\text{watts} = \text{amperes} \times \text{volts}.$$

Watts (in both M and R)

$$= \text{amperes (through both)} \times \text{volts (across both)}.$$
$$4 \times 120 = 480 \text{ watts.}$$

This checks with the value of power, 480 watts, obtained by adding the power consumed by each.

When the voltage and current for each part of a circuit are not given, they can be found by applying Ohm's Law to that part of the circuit, and then applying the power equation to find the watts consumed.

Example 5. What power is consumed by an incandescent lamp of 200 ohms resistance, when burning on a 110-volt circuit?

First Step. (Find amperes and volts.)

$$\begin{aligned}\text{Amperes} &= \frac{\text{volts}}{\text{ohms}}\\ &= \tfrac{110}{200}\\ &= 0.55 \text{ ampere.}\end{aligned}$$

Second Step. (Compute power.)

$$\begin{aligned}\text{Watts} &= \text{amperes} \times \text{volts}\\ &= 0.55 \times 110.\\ \text{Power} &= 60.5 \text{ watts.}\end{aligned}$$

Prob. 17-4. The generator G, Fig. 85, furnishes 1.8 ampere to the line at 125 volts pressure. What power is consumed:

(*a*) By the lamp L, and

(*b*) By the 10-ohm resistance R?

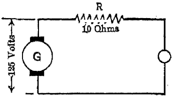

FIG. 85. Lamp and resistor in series with generator.

Prob. 18-4. What power does a car heater use if its resistance is 220 ohms and the pressure across it is 550 volts?

Prob. 19-4. What power does an electric flatiron use on a 115-volt circuit if its resistance is 25 ohms?

Prob. 20-4. A 110-volt arc lamp requires 9.6 amperes to operate properly. What power does such a lamp take?

Prob. 21-4. What power is consumed by each lamp in the group of lamps of Prob. 9-3?

Prob. 22-4. A heater has a resistance of 50 ohms and takes a current of 2.7 amperes. What power does it consume?

Prob. 23-4. A telegraph line has 2500 ohms resistance. What power is consumed when 0.004 ampere is sent through it?

31. Line Loss. Since it requires power to keep a current flowing against resistance, there must be some power used

in keeping the current flowing through the line wires of any system. Of course, all the power used in this way is wasted and it is, therefore, called the **Line Loss.** Line loss is measured in watts just as any other electrical power, and is the product of the volts times the amperes, **of the line wires alone.** That is,

watts (lost in line) = volts (drop in line wires) × amperes (through line wires).

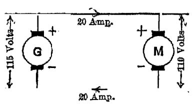

FIG. 86. The line loss is 100 watts.

Consider Fig. 86. Since the generator supplies 115 volts and the motor gets only 110 volts, 5 volts must be used in forcing the current through the line.

Watts (lost in line wires) = volts (used in line wires) × amperes (through line wires).

$$5 \times 20 = 100 \text{ watts.}$$

Or, consider the problem in this manner.

The generator (*G*) is supplying 20 amperes at 115 volts to the system. The motor (*M*) is taking 20 amperes at 110 volts. Thus,

generator supplies 20 × 115 = 2300 watts,
motor takes 20 × 110 = 2200 watts.
There must be lost in line 100 watts.

This value of the line loss checks with the first way of finding it.

Prob. 24-4. How many watts are consumed in the lead wires in Fig. 50 if their resistance is 1.5 ohms each?

Prob. 25-4. How many watts are used by the motor *M* in Prob. 9-3? How many watts by the line wires between *G* and *M*?

32. Kilowatt and Horse Power. Since the watt is a unit of power too small to express conveniently the rating

of modern electrical machinery, a unit called the **Kilowatt,** equal to 1000 watts, is generally used.

Thus:

2500 watts would be $\frac{1}{1000}$ of 2500, or 2.5 kilowatt
and 450 " " " $\frac{1}{1000}$ " 450, " 0.45 "

Example 6. What power does a motor consume which takes 20 amperes at 220 volts?

$$\begin{aligned} \text{Watts} &= 20 \times 220 \\ &= 4400 \text{ watts.} \\ \text{Kilowatts} &= \tfrac{4400}{1000} = 4.4 \text{ kilowatts.} \end{aligned}$$

Since a kilowatt is a unit of power it can be reduced to horse power.

$$\textbf{1 kilowatt} = \mathbf{1\tfrac{1}{3}} \textbf{ horse power,}$$

or

$$\textbf{1 horse power} = \mathbf{\tfrac{3}{4}} \textbf{ kilowatt.}$$

Example 7. What horse power does the motor of the above example consume?

$$\begin{aligned} 1 \text{ kilowatt} &= 1\tfrac{1}{3} \text{ horse power} \\ 4.4 \text{ kilowatts} &= 4.4 \times 1\tfrac{1}{3} \text{ horse power} \\ &= 5.87 \text{ horse power.} \end{aligned}$$

Example 8. The output of a 10-horse-power motor could be rated as how many kilowatts?

$$\begin{aligned} 1 \text{ horse power} &= \tfrac{3}{4} \text{ kilowatt.} \\ 10 \text{ horse power} &= 10 \times \tfrac{3}{4} \text{ kilowatt.} \\ &= 7.5 \text{ kilowatts.} \end{aligned}$$

It has become customary to rate machinery in terms of its output, machines having electrical output such as generators being rated in kilowatts and those having mechanical output such as motors being rated in horse power.

Prob. 26–4. What power in kilowatts and in horse power does a 115-volt lamp consume when it takes a current of 0.76 ampere?

Prob. 27–4. Express the answer to Prob. 17–4 in kw. and h.p.

Prob. 28-4. Express the answer to Prob. 18-4 in kw. and h.p.

Prob. 29-4. " " " " 20-4 " "

Prob. 30-4. " " " " 22-4 " "

33. Efficiency of Electrical Apparatus. No electrical machine gives out all the power it receives. The percentage which it does give out is called its **efficiency.** Thus a motor that gives out 9 kilowatts for every 10 kilowatts it receives, is said to have an efficiency of 90 per cent. If it gives out only 8 kilowatts for every 10 kilowatts it receives, it has an efficiency of only 80 per cent.

The power a machine receives is called the **input.** The power it gives out is called the **output.** The efficiency may be said to be the ratio of the output to the input, or

$$\textbf{efficiency} = \frac{\textbf{output}}{\textbf{input}}.$$

Since the output is always smaller than the input, the fraction $\frac{\text{output}}{\text{input}}$ is always less than unity, and is stated as a per cent, as 75 per cent, 90 per cent, etc. Another way of stating the same fact is: The efficiency of any device is always less than 100 per cent. Of course, the output and the input must always be stated in the same units. We cannot compare the input of a motor in kilowatts to the output in horse power. They must both be reduced either to kilowatts or to horse power.

Example 9. A 5-horse-power motor takes 4.8 kilowatts to operate it. What is the efficiency of the motor?

Reduce both output and input to horse power.

$$4.8 \text{ kilowatts} = 4.8 \times 1\tfrac{1}{3} = 6.4 \text{ horse power.}$$

$$\text{Efficiency} = \frac{\text{output}}{\text{input}}$$

$$\frac{5}{6.4} = 78.2 \text{ per cent,}$$

or

reduce both output and input to kilowatts.

$$5 \text{ horse power} = \tfrac{3}{4} \times 5 = 3.75 \text{ kilowatts.}$$

$$\text{Efficiency} = \frac{\text{output}}{\text{input}}$$

$$= \frac{3.75}{4.8} = 78.2 \text{ per cent.}$$

Prob. 31–4. A motor having an efficiency of 85 per cent takes 2 kilowatts. What horse power will it deliver?

Prob. 32–4. What power in kilowatts is required to operate a 12-horse-power motor having an efficiency of 90 per cent?

Prob. 33–4. What current will the motor of Prob. 31–4 require if the motor is built for 115 volts?

Prob. 34–4. For what voltage is the motor of Prob. 32–4 built if it requires 45.2 amperes?

Prob. 35–4. A 110-volt motor taking 25 amperes has an efficiency of 85 per cent. What horse power will it deliver?

Prob. 36–4. What full-load current does a 1-horse-power, 115-volt motor take if its efficiency is 70 per cent?

Prob. 37–4. An engine supplies 178 horse power to a generator delivering 210 amperes at 550 volts. What is the efficiency of the generator?

Prob. 38–4. A generator delivers a current of 75 amperes at a pressure of 110 volts. What power does it supply in kilowatts? In horse power?

Prob. 39–4. An engine supplies 150 horse power to a generator delivering 173 amperes at a pressure of 550 volts. What is the efficiency of the generator?

34. Work and Energy. Horse-power-hour. Kilowatt-hour. When a man buys mechanical power to run his shop he has to pay not only according to the horse power he uses but also according to the number of hours he uses the power. For instance, he may use 40 horse power for 1 hour and pay \$1.20 for it, that is, at the rate of 3 cents for each horse-

power-hour. If he uses 40 horse power for 2 hours he would have to pay twice as much, because he has used the same power twice as long. Another way of stating the same fact is to say that he used twice as many horse-power-hours. For in the first instance he used 40×1, or 40 horse-power-hours, and in the second 40×2, or 80 horse-power-hours. In other words, he did twice as much work in the second case as he did in the first, or received twice as much energy. The unit of work or energy then is the **horse-power-hour**, and is the work done in 1 hour by a 1-horse-power machine.

Example 10. How much work is done by a machine delivering 15 horse power when it is run for 8 hours?

1 h.p. in 1 hour does 1 horse-power-hour,
15 h.p. in 1 hour does 15 horse-power-hours,
15 h.p. in 8 hours does 8×15, or 120 horse-power-hours,

or

$$\text{work} = \text{horse power} \times \text{hours},$$
$$15 \times 8 = 120 \text{ horse-power-hours}.$$

Example 11. At 3 cents per horse-power-hour how much does it cost to run a 200-horse-power engine for 12 hours?

$$\begin{aligned}\text{Horse-power-hours} &= 200 \times 12 \\ &= 2400 \text{ horse-power-hours.}\end{aligned}$$
$$\text{Cost} = 3 \text{ cents} \times 2400 = \$72.00.$$

Prob. 40–4. What does it cost to run a 15-horse-power engine 6 working days of 8 hours each at $1\frac{1}{2}$ cents per horse-power-hour?

Prob. 41–4. A man's bill for 38 hours was \$24.00. If he paid at the rate of 3 cents per horse-power-hour, what average power was delivered to him?

Prob. 42–4. A man pays 2 cents per horse-power-hour for power. How long can he use 20 horse power and not have a bill to exceed \$100.00?

Similarly, electric power is sold by the **kilowatt-hour.** This unit is the work or energy delivered in 1 hour by a 1-kilowatt machine.

Example 12. A generator delivers 2 kilowatts to a consumer for 40 hours. How much electrical energy is consumed by the customer?

$$\begin{aligned}\text{Kilowatt-hours} &= \text{kilowatts} \times \text{hours}\\ &= 2 \times 40 = 80 \text{ kilowatt-hours.}\end{aligned}$$

Prob. 43–4. How much electrical energy is consumed in 40 hours by a motor which requires 18 kilowatts?

Prob. 44–4. What will be the cost of using 48 kilowatts for 30 hours at 7 cents per kilowatt-hour?

Prob. 45–4. For how many hours can a 200-kilowatt motor be run on $50.00 if electrical energy costs 2 cents per kilowatt-hour?

It is always possible to determine the electrical energy used by any appliance when the volts, amperes, and hours are known. In case the load changes, the energy must be computed for each condition and the results added to give the total. For example, if during a day, the load in a house is 10 amperes for 3 hours, 7 amperes for 2 hours, and 3 amperes for 5 hours, and no load for the other 14 hours, all at 110 volts, the total energy for the day would be found as follows:

Volts × amperes ÷ 1000 = kw.	Kilowatts × hours = kw.-hr.
$\frac{110 \times 10}{1000}$ 1.1 kw.	$1.1 \times 3 = 3.3$ kw.-hr.
$\frac{110 \times 7}{1000} = 0.77$ kw.	$0.77 \times 2 = 1.54$ kw.-hr.
$\frac{110 \times 3}{1000} = 0.33$ kw.	$0.33 \times 5 = 1.65$ kw.-hr.
	Energy per day = 6.49 kw.-hr.

If the load changes often, this method of calculation would be difficult if not impossible practically to apply. A meter called a watt-hour meter (see Fig. 260) is commonly used to

SUMMARY OF CHAPTER IV

WATT is the small unit of electric power; power in watts equals volts × amperes.

KILOWATT equals 1000 watts; equals $1\frac{1}{3}$ horse power.

HORSE POWER equals $\frac{3}{4}$ kilowatt.

POWER (in watts) consumed by any part of a circuit equals the product of the current flowing through THAT PART of the circuit times the voltage across JUST THAT SAME PART of the circuit.

EFFICIENCY is the fraction of the power put into a device which is delivered by the device. This is expressed as a per cent. Since a machine never delivers all the power put into it, this is always less than 100 per cent.

ENERGY AND WORK. Mechanical energy is measured commercially by the horse-power-hour; equals (horse power) × (hours).

Electrical energy is measured commercially by the kilowatt-hour; equals (kilowatts) × (hours).

PROBLEMS ON CHAPTER IV

Prob. 46–4. How much will it cost at 4 cents per kilowatt-hour to run a 110-volt motor for 8 hours? Motor takes 35 amperes.

Prob. 47–4. How much electrical energy is changed into heat when a 60-watt lamp is burned for 20 hours?

Prob. 48–4. At 8 cents per kilowatt-hour, what is the cost of running the iron in Prob. 12–4 for 6 hours?

Prob. 49–4. The three-section roasting oven shown in Fig. 87 is rated at 4.5 kilowatts per section and operates on 110 volts. (*a*) How much power is required when one section is turned on? (*b*) How much power is required when all three sections are turned on? (*c*) If the oven is used 5 hours a day with all three sections on, how much energy does it consume daily?

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Prob. 50–4. At 2.5 cents a kilowatt-hour, how much will it cost a day to run the roasting oven of Prob. 49–4 if one section is on 2 hours, two sections are on 3 hours, and three sections are on 4 hours each day?

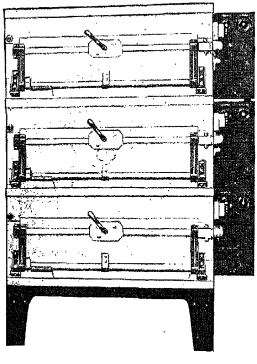

FIG. 87. Three-section roasting oven. *Westinghouse Electric & Manufacturing Co.*

Prob. 51–4. What current must be provided for by the electrician when the roasting oven of Prob. 49–4 is installed?

Prob. 52–4. The roasting oven of Prob. 49–4 may be procured with heating elements of the same power rating but designed to operate on 220 volts. What current would the electrician have to provide for in this case?

Prob. 53–4. The early carbon-filament incandescent lamps had an efficiency of 2.5 lumens (units of light flux) per watt as compared with 10 lumens per watt for the vacuum-type tungsten lamps, and 20 lumens per watt for the gas-filled 1000-watt tungsten lamps. If the price of electrical energy has dropped to two-thirds its value in the early years of lighting, find the decrease in the cost of illumination, based on equal intensities in the different cases.

Prob. 54–4. A certain electric lamp takes 0.232 ampere at 108 volts. What is its rating in watts?

Prob. 55–4. A resistor carries a current of 2 amperes and absorbs 46 watts. What is its resistance?

Prob. 56–4. A resistor having a resistance of 15 ohms is placed across a voltage of 220 volts. What power does it take?

Prob. 57–4. A resistor having a resistance of 15 ohms is carrying a current of 21 amperes. How many watts does it consume?

Prob. 58–4. What work is done in maintaining for 12 hours a current of 100 amperes in a wire of 1.6 ohm resistance?

Prob. 59–4. A bill for electric energy was $16.40 for 120 hours. If the price was 9 cents per kilowatt-hour, what was the average power used?

Prob. 60–4. When 100 incandescent lamps had been burned on a 110-volt circuit for 4 hours, a bill of $4.00 was presented, computed at the rate of 8 cents per kilowatt-hour. What was the average current taken by each lamp?

Prob. 61–4. At 3 cents per kilowatt-hour, how much does it cost per year for transmission losses in Fig. 71? Lamps are burned 3 hours each day.

Prob. 62–4. What is the total energy lost in the line wires per month of 120 hours in Fig. 69?

Prob. 63–4. At 7 cents per kilowatt-hour how long can two 110-volt tungsten lamps be burned for $1.00? Resistance of each lamp is 250 ohms.

Prob. 64–4. What is the efficiency of a transmission line that receives 5 kilowatts at 115 volts and delivers power at 110 volts?

Prob. 65–4. How much power is delivered under the conditions of Prob. 64–4? What is the line loss?

Prob. 66–4. (*a*) What is the line loss in Prob. 9–3? (*b*) What is the efficiency of transmission in Prob. 9–3?

Prob. 67–4. A 110-volt tungsten lamp has a resistance of 121 ohms. How much power does it take?

Prob. 68–4. An electric clock requires 2 watts for its operation. How much does it cost to run it per year if electrical energy sells for 8 cents a kilowatt-hour?

Prob. 69–4. What power is required to charge a storage battery if it takes 175 amperes at 117 volts?

Prob. 70–4. If in Prob. 69–4 the value of current is kept constant and the given voltage is an average over a period of 8 hours, how many kilowatt-hours of electrical energy are used in the 8-hour charge?

Prob. 71–4. A carbon arc lamp equipped with ballast series resistance is operated on a 110-volt circuit. The arc itself re-

quires 9.5 amperes at 52 volts. How much power is consumed by the arc and how much is wasted in the ballast resistance?

Prob. 72–4. What is the cost of burning for 6 hours, five 50-watt lamps? Price of electric energy is 10 cents per kilowatt-hour.

Prob. 73–4. A 16-candle-power lamp is rated at 3 watts per candle power. What will it cost to burn the lamp 100 hours at 12 cents per kilowatt-hour?

Prob. 74–4. What is the cost of burning, per month of 150 hours, three 20-candle-power lamps which are rated at $1\frac{1}{2}$ watts per candle power? Electricity costs 11 cents per kilowatt-hour.

Prob. 75–4. How many 50-watt lamps can be burned for a month of 100 hours and not cost over $2.00? (Electricity at 12 cents per kilowatt-hour.)

Prob. 76–4. What full-load efficiency has an 8-horse-power motor which requires 63 amperes at 112 volts?

Prob. 77–4. A generator has an efficiency of 88 per cent. What current can it deliver at a pressure of 220 volts when it receives 100 horse power from the driving engine?

Prob. 78–4. What is the efficiency of a 3.5-horse-power motor if the input is 3.5 kilowatts?

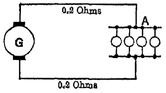

FIG. 88. Not all the power delivered by the generator is received by the lamps.

Prob. 79–4. The lamp bank A, Fig. 88, uses 3 amperes at 110 volts.

(a) What power is lost in the line?

(b) What power is used by each lamp?

(c) What power is delivered by generator?

Prob. 80–4. The efficiency of the generator in Prob. 79–4 is 95 per cent. How much power does it receive? (Answer to be in horse power.)

Prob. 81–4. Electrical energy for lighting costs 15 cents per kilowatt-hour. What is the cost per month (30 days) of operating a 16-candle-power lamp, which takes 2.5 watts per candle power, the lamp being in service 3 hours each day?

Prob. 82–4. Electrical energy is supplied at 5 cents per kilowatt-hour for driving a 25-horse-power motor. The efficiency

of the motor at full load is 83 per cent. Find the cost of operating the motor for 100 hours.

Prob. 83–4. The generator, Fig. 89, delivers 7 kilowatts to the line. The motor uses 6.6 kilowatts.

Find:

(*a*) Watts lost in line.
(*b*) Voltage and current of motor.
(*c*) Brush voltage of generator.

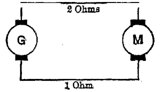

FIG. 89. Generator *G* must deliver enough power to supply line losses as well as power required by motor *M*.

Prob. 84–4. An iron wire is to be used as an electric heater. The wire has a resistance of 0.004 ohm per foot. How many feet of wire must be used to absorb 2.4 kilowatts, if the wire is to carry 20 amperes?

Prob. 85–4. A motor takes 14 kilowatts. The resistance of the lead wires is 0.08 ohm each.

(*a*) How much power is lost in the leads if the voltage of the motor is 110 volts?

(*b*) If the voltage of the motor is 220 volts?

Prob. 86–4. What must be the pressure at the generator in Prob. 85–4 (*a*) and (*b*)?

Prob. 87–4. At 4 cents per kilowatt-hour, how much is the energy worth which is lost per year of 300 days of 10 hours each, in the lead wires of Prob. 85–4 (*a*) and (*b*)?

Prob. 88–4. What does it cost to run an electric car a mile, if 60 amperes at 550 volts drive a car at an average rate of 15 miles per hour? (Electricity to cost 1.5 cents per kilowatt-hour.)

Prob. 89–4. What does it cost at 8 cents per kilowatt-hour to use eight 16-candle-power incandescent lamps for 6 hours, if each lamp takes 3 watts per candle power?

Prob. 90–4. (*a*) In Prob. 4–3, how much power is taken by each of the filaments?

(*b*) How much power is lost in each of the rheostats?

(*c*) What is the total power supplied by the "A" battery?

Prob. 91–4. (*a*) What power is taken by each lamp under the conditions of Prob. 41–3 (*b*)?

(*b*) What is the total power supplied to the bank of lamps?

CHAPTER V

WIRE AND WIRING SYSTEMS

35. Insulators and Conductors. Some substances conduct electricity more readily than do others. Accordingly, we speak of one material as an insulator if electricity flows through it with great difficulty while another material is classed as a conductor if electricity flows through it with relative ease.

The more common insulators are porcelain, glass, mica, bakelite, guttapercha, varnished cambric, jute and paper, the latter four being used extensively in the construction of electric power and communication cables.

The best conductors in their order of decreasing resistance are the metals silver, copper, gold and aluminum. Of these four, the cheaper price of copper and aluminum commends them to general use as electrical conductors. These two are in sharp competition in the field of power transmission lines, but copper is used almost exclusively for interior wiring due to its greater toughness and smaller size for wires of a given carrying capacity. The fire hazard is greater in the case of aluminum because of its lower melting temperature.

In order to find out how to compute the resistance of a piece of wire, it will be interesting to note separately the effects of length and diameter.

36. Effect of Length on the Resistance. A round copper wire 0.1 inch in diameter has a resistance of about 1 ohm per 1000 feet. The resistance of 2000 feet of this wire would have twice as much resistance as 1000 feet or 2 ohms, since the resistance of a series combination is the sum of the resistances of its separate parts. Likewise, the resistance of

10,000 feet of this wire would be 10 times the resistance of 1000 feet. The resistance of a given size of wire is thus seen to be the resistance of 1000 feet multiplied by the number of thousand feet, or it is the resistance of 1 foot multiplied by the number of feet.

Example 1. The resistance of 1 foot of copper wire of a certain size is 2.521 ohms per 1000 feet. What is the resistance of 400 feet?

$$\begin{aligned} \text{Resistance of 1000 feet} &= 2.521 \text{ ohms.} \\ \text{Resistance of 400 feet} &= 0.4 \times 2.521. \\ &= 1.01 \text{ ohms.} \end{aligned}$$

Prob. 1–5. The smallest rubber-covered copper wire used in house lighting lines has a resistance of 2.521 ohms per 1000 feet. (*a*) What is the resistance of a mile of this wire? (*b*) What would be the resistance of a two-mile, two-wire line of this wire?

Prob. 2–5. The smallest copper wire allowable for exterior use in electric lighting has a resistance of 1.586 ohms per 1000 feet. What is the resistance of a 2-wire, 250-foot lead-in circuit of this wire?

Prob. 3–5. The resistance of 1 foot of a certain size wire is 0.082 ohm. How many feet of this wire will it take to make a resistance of 30 ohms?

Prob. 4–5. If the resistance of 900 feet of a certain size wire is 0.223 ohm, what is the resistance of 1500 feet?

37. Effect of Size on the Resistance. The effect of increasing or decreasing the size is a little more difficult to understand.

Let us assume for a moment that copper wires are drawn square instead of round. Assume a certain square wire to measure 1 inch on each side. The area of the end of the wire (generally called the " cross-section area ") would then be 1 square inch.

If we take a square wire 2 inches on each side, its cross-section area would be 2 × 2, or 4 square inches. Thus (*a*), Fig. 90, represents the end view of a square wire 1 inch on

a side, while (*b*) represents the end view of a wire 2 inches on a side.

Note that although the side of (*b*) is only twice as great as that of (*a*), the area of (*b*) is four times that of (*a*). In other words, four 1-inch wires could be made out of a 2-inch

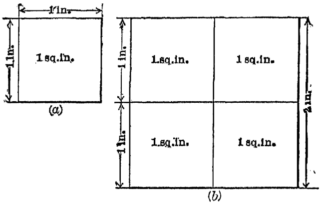

FIG. 90. The side of (*b*) is twice the side of (*a*) but the area of (*b*) is 4 times the area of (*a*).

wire. The figure clearly shows that the 2-inch wire contains enough material to make four 1-inch wires.

In the same way it will be seen that if we make a square wire 3 inches on a side, the area of the end will be 3×3, or 9 square inches. A wire 3 inches on a side will then make 9 wires 1 inch on a side. Similarly a 5-inch wire will make 25 wires 1 inch on a side, etc.

Note that in each case as we increase the length of the side a given number of times, we increase the end area the **square of that number of times**, and the number of small wires that the larger one is equivalent to, is also the **square** of that number.

Thus:

(*a*) A 2-in.	wire	has	4	sq. in.	area	and is equal to	4 1-in. wires.
(*b*) A 3	"	"	9	"	"	" "	9 1-in. wires.
(*c*) A 4	"	"	16	"	"	" "	16 1-in. wires,

etc.

If we had a square copper wire 1 foot long and $\frac{1}{100}$ inch on a side, it would have a resistance of 0.081 ohm.

Now if we had a square copper wire 1 foot long but $\frac{2}{100}$ inch on a side, it would make 4 wires 1 foot long and $\frac{1}{100}$ inch on a side, since it would have twice the length of side of the $\frac{1}{100}$-inch wire. Thus the $\frac{2}{100}$-inch wire is equivalent to four $\frac{1}{100}$-inch wires 1 foot long laid side by side. This would be equivalent to placing four $\frac{1}{100}$-inch wires 1 foot long in parallel. So the resistance of 1 foot of $\frac{2}{100}$-inch square wire is equal to the resistance of four $\frac{1}{100}$-inch wires each 1 foot long placed in parallel, as is shown in Fig. 91.

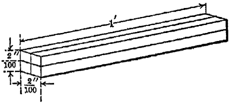

FIG. 91. One wire 2 in. square makes 4 wires 1 in. square.

An electric current could then go through the larger wire **four** times as easily as through the smaller wire. In other words, the **resistance** is only **one-fourth** as much, as we have seen on page 39.

Thus, if the resistance of 1 foot of $\frac{1}{100}$-inch square copper wire is 0.081 ohm, the resistance of 1 foot of $\frac{2}{100}$-inch square copper wire would be $0.081 = 0.0203$ ohm. Similarly, the resistance of 1 foot of $\frac{3}{100}$-inch square copper wire would be $\frac{0.081}{9} = 0.009$ ohm, etc.

Note that if we know the resistance of a foot of any square wire of unit length of side, we can find the resistance of a foot of square wire of any length of side, by **dividing** by the **square** of the number of these units in the side. This amounts to dividing the resistance of the unit wire by the number of unit wires of which this wire may be assumed to be composed.

Example 2. Assume a square unit wire $\frac{1}{1000}$ inch on a side and 1 foot long, has a resistance of 8.16 ohms. What would be

the resistance of a square wire 1 foot long and $\frac{8}{1000}$ inch on a side?

Resistance of 1 ft. of wire $\frac{1}{1000}$ inch on a side $= 8.16$ ohms,

1 ft. $\frac{8}{1000}$ " " " $\frac{8.16}{(8)^2} = \frac{8.16}{64}$ "

$= 0.127$ ohm.

For a wire $\frac{8}{1000}$ inch on a side is equivalent to 8×8, or 64 wires $\frac{1}{1000}$ inch on a side, laid side by side, or in parallel. The resistance of an $\frac{8}{1000}$-inch wire therefore equals $\frac{1}{64}$ of 8.16 ohms $= 0.127$ ohm.

Example 3. On the basis of Example 2 what would be the resistance of a square copper wire 0.415 inch on a side?

$$0.415 = \frac{415}{1000}.$$

Thus, this wire would be equal to 415×415, or 172,000 wires $\frac{1}{1000}$ inch on a side, laid in parallel.

Resistance of 0.415-inch wire then equals

$$\frac{8.16}{172{,}000} = 0.0000474 \text{ ohm},$$

or

A square wire $\frac{1}{1000}$ inch on a side has 8.16 ohms resistance,

" " " $\frac{415}{1000}$ " " " $\frac{8.16}{415 \times 415} = 0.0000474$ ohm.

Prob. 5-5. Assuming the resistance of a unit square wire as in Example 2, what is the resistance of 1 foot of square copper wire 0.045 inch on a side?

Prob. 6-5. On the same basis, what is the resistance of 1 foot of square copper wire 0.5 inch on a side?

Prob. 7-5. On the same basis, what must be the length of side of 1 foot of square copper wire, to have a resistance of 0.0835 ohm?

38. Circular Wire. As most copper wire is drawn round instead of square, we must be able to compute the resistance of such wire.

It may be said at once that all statements concerning square wire apply equally to round wire. That is:

(1) The resistance of any length of round wire is equal to the resistance of 1 foot of that wire multiplied by the length in feet.

(2) If the resistance of 1 foot of round copper wire $\frac{1}{1000}$ inch in diameter is known, then the resistance of 1 foot of any size round wire is equal to this known resistance divided by the **square** of the number of thousandths in the diameter.

The first statement is obvious; the second requires corroboration.

We have seen how a square wire 3 inches in diameter is equal to 3×3, or 9 square wires 1 inch in diameter, laid side by side. Similarly, a round wire 3 inches in diameter is equal to 3×3, or 9 round wires 1 inch in diameter, laid side by side.

Thus, in Fig. 92 it can be shown that the 3-inch circle has exactly the same area as the **nine** 1-inch circles combined, and will contain **nine** 1-inch circles, if we consider that the parts projecting beyond the large circle are to be used up in filling in the chinks left inside the large circle. Therefore, the large circle can be thought of as being composed of small circles of unit diameter. There are as many small circles in the large one as the square of the diameter of the large one. Accordingly, a round wire $\frac{5}{1000}$ inch in diameter is equal to 5×5, or 25 round wires $\frac{1}{1000}$ inch in diameter laid side by side, or in parallel. If we knew the resistance of the $\frac{1}{1000}$-inch wire, then we would know that the resist-

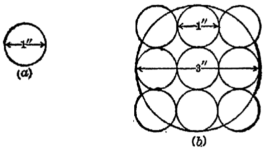

FIG. 92. The diameter of (b) is 3 times the diameter of (a) but the area of (b) is 9 times the area of (a).

ance of the $\frac{5}{1000}$-inch wire was $\frac{1}{25}$ of the resistance of the $\frac{1}{1000}$-inch wire.

The mathematical proof of the fact that a circle 3 inches in diameter contains the area of 9 circles, 1 inch in diameter, is as follows:

Area of circle 1 inch in diam. $= 0.7854 \times 1 \times 1 = 0.7854$ sq. in.
" " 3 " " $= 0.7854 \times 3 \times 3 = 7.069$ "

There are then as many circles 1 inch in diameter in a circle 3 inches in diameter as

0.7854 sq. in. is contained in 7.069 sq. in., or 9.

Therefore a circle 3 inches in diameter contains

3×3, or 9 circles 1 inch in diameter.

In the same way it can be proved that a 5-inch circle contains 5×5, or 25 1-inch circles, etc.

39. Mil. A round wire 1 foot long and $\frac{1}{1000}$ inch in diameter has been adopted as the unit round wire. The diameter $\frac{1}{1000}$ inch is called a **mil.** The term " mil " always means $\frac{1}{1000}$. In our coinage a " mill " is $\frac{1}{1000}$ of a dollar. A millivolt is $\frac{1}{1000}$ volt, etc. When it is spelled " mil " it always means $\frac{1}{1000}$ inch. Thus a wire of 1 mil in diameter is a wire $\frac{1}{1000}$ inch in diameter. A wire 25 mils in diameter is $\frac{25}{1000}$ inch in diameter, etc. Instead of saying " thousandth inch " we say " mil " in speaking of the diameter of wire.

Prob. 8–5. How many mils in 0.75 inch?

Prob. 9–5. A wire has a diameter of 0.204 inch. What is the diameter in mils?

Prob. 10–5. What is the diameter in mils of a wire 0.460 inch in diameter?

Prob. 11–5. A wire has a diameter of 64.08 mils. What is its diameter in inches?

40. Mil-foot. Circular Mil. The unit wire is a round wire 1 foot long and 1 mil in diameter, and is called a **mil-foot wire.**

Now we have found that a wire of more than $\frac{1}{1000}$ inch or 1 mil in diameter will contain as many unit wires as the square of the number of mils or thousandths in its diameter. Thus, a wire 8 mils in diameter is equivalent to 64 wires 1 mil in diameter. Another way of saying this is to say that the end area of a round wire 1 mil in diameter is 1 **circular mil**, to distinguish it from a square wire. Then the end area of a wire $\frac{8}{1000}$ inch in diameter would be 8×8, or 64 circular mils.

The circular mil area of a wire, then, is the number of unit circles which it will contain, a unit circle being a circle 1 mil in diameter. Since any circle will contain as many unit circles as the square of the diameter in mils, we say that the area of a circle in circular mils equals the square of the diameter in mils.

Thus, the area of a circle 4 mils in diam. is $4 \times 4 = 16$ cir. mils.
Area of circle 60 mils in diam. is $60 \times 60 = 3600$ cir. mils.
Area of circle 250 mils in diam. is $250 \times 250 = 62{,}500$ cir. mils, etc.

This method of stating the area of a circle is much easier and more sensible than finding the area in square inches, which always involves the value 3.1416. It is merely finding the number of unit circles contained in a circle, instead of the number of unit squares. The number of unit circles (circular mils) is always the square of the diameter in mils.

Example 4. What is the area in circular mils of a circle $\frac{1}{2}$ inch in diameter?

$\frac{1}{2}$ inch $\frac{500}{1000}$ inch 500 mils.
Area = 500×500 250,000 circular mils.

Example 5. How many unit wires would 1 foot of wire $\frac{1}{4}$ inch in diameter contain?

$\frac{1}{4}$ inch $= \frac{250}{1000}$ inch $= 250$ mils.
Area $= 250 \times 250 = 62{,}500$ circular mils.
Area of unit wire = 1 circular mil.

Wire of 62,500 cir. mils then contains $\frac{62{,}500}{1} = 62{,}500$ unit wires.

Prob. 12–5. What is the circular mil area of a wire 0.325 inch in diameter?

Prob. 13–5. What is the circular mil area of wire 0.102 inch in diameter?

Prob. 14–5. Find the circular mil area of a circle 0.003145 inch in diameter.

Prob. 15–5. How many unit wires will a wire 0.0285 inch in diameter make?

Prob. 16–5. To how many unit wires is a wire 1 inch in radius equivalent?

Prob. 17–5. What is the diameter of a wire containing 2500 circular mils?

Prob. 18–5. What is the diameter of a wire containing 16,900 circular mils?

Prob. 19–5. What area in circular mils will a circle 1.04 inches in diameter have?

41. Effect of Length and Diameter upon the Resistance of Wire. We have defined a unit wire as a round wire 1 foot long and 1 mil in diameter (or having an end area of 1 circular mil). This unit wire is called a mil-foot and when made of copper has a resistance of 10.4 ohms. This is usually stated as follows:

The resistance per mil-foot of copper is usually taken as 10.4 ohms. This statement should be memorized carefully as all calculations of copper wire are based on it, and from it we may compute the resistance of any length of any size copper wire.

For if we know the resistance of 1 foot of round wire 1 mil in diameter, then we can compute the resistance of 1 foot of any size round wire as follows:

To find the resistance of 1 foot of copper wire $\frac{6}{1000}$ inch in diameter, we say that the resistance of 1 foot of copper wire having 1 mil diameter is 10.4 ohms. A wire having $\frac{6}{1000}$ inch, or 6 mils, diameter is equivalent to 6×6, or

36 wires 1 mil in diameter, laid side by side, since it contains 6×6, or 36 circular mils end area. The resistance then of 1 foot of 6-mil wire would be $\frac{10.4}{36} = 0.289$ ohm, or

$$\begin{array}{ll} \text{Resistance of 1 foot of wire 1 mil in diam.} & 10.4 \text{ ohms,} \\ \text{" \quad 1 foot " \quad 6 " \quad "} & = \dfrac{10.4}{6 \times 6} \\ & = 0.289 \text{ ohm.} \end{array}$$

But we have seen that if we know the resistance of 1 foot of any wire, we can find the resistance of any number of feet by simply multiplying by the length. Thus, if the resistance of 1 foot of copper wire 6 mils in diameter is 0.289 ohm, as found above, then the resistance of 1000 feet of this wire would be $0.289 \times 1000 = 289$ ohms.

Thus, to find the resistance of any length of any size wire:

> **Multiply the resistance of unit wire (1 mil-foot) by the length in feet and divide by the square of the mil diameter (circular mil area).**

Example 6. What is the resistance of one mile of copper wire 0.125 inch in diameter?

$$\begin{array}{ll} \text{Resistance of 1 ft. of wire \quad 1 mil in diam.} & = 10.4 \text{ ohms,} \\ \text{" \quad " 1 ft. " \quad 125 mils \quad "} & = \dfrac{10.4}{125 \times 125} \\ & = 0.000667 \text{ ohms.} \end{array}$$

Resistance of 5280 ft. of wire 125 mils in diam.

$$= 0.000667 \times 5280$$
$$= 3.52 \text{ ohms,}$$

or

$$\textbf{Res. of wire} = \frac{\textbf{resistance per mil-foot} \times \textbf{length in feet}}{\textbf{circular mil area}},$$

$$\frac{10.4 \times 5280}{125 \times 125} \quad 3.52 \text{ ohms.}$$

Prob. 20-5. How many feet of copper wire 0.04 inch in diameter will it take to make a resistance of 4 ohms?

Prob. 21-5. What will be the resistance of 900 feet of copper wire 0.25 inch in diameter?

Prob. 22-5. What diameter must copper wire have in order that one mile of it may have a resistance of 0.196 ohm?

Prob. 23-5. What is the resistance of 2 miles of 0.32 mil copper wire?

Prob. 24-5. What is the circular mil area of a wire $\frac{5}{16}$ inch in diameter?

Prob. 25-5. What resistance will 2000 feet of copper wire of the size in Prob. 24-5 have?

Prob. 26-5. What resistance has 525 feet of a copper wire of 9876 circular mil area?

Prob. 27-5. What is the radius of the wire in Prob. 26-5?

Prob. 28-5. What is the resistance of 6 miles of copper wire $\frac{3}{8}$ inch in diameter?

Prob. 29-5. How many miles of copper wire $\frac{1}{2}$ inch in diameter will it take to make 3 ohms of resistance?

Prob. 30-5. The distance between a motor and a generator is 800 feet. The copper line wires are 0.130 inch in diameter. What is the resistance of the line?

Prob. 31-5. Ordinary fixture wire usually has a diameter of 0.040 inch. What is the resistance per 1000 feet?

Prob. 32-5. Annunciator wire generally has a diameter of 0.040 inch. How many feet does it take to make a resistance of 2 ohms?

Prob. 33-5. How many feet of the wire in Prob. 31-5 does it take to produce 1 ohm?

Prob. 34-5. The line wires in Fig. 33 are each 400 feet long. Of what diameter must they be?

Prob. 35-5. How long is each line wire in Fig. 27 if each has a diameter of 0.064 inch?

Prob. 36-5. In Fig. 57 what size wire is used? The distance from the generator to the lamps is 500 feet.

Prob. 37-5. What is the resistance of 6 miles of copper wire $\frac{7}{16}$ inch in diameter?

42. Drop Along a Line Wire. Knowing the length and the size of a line wire and the current it is to carry, we are able to compute the voltage drop in the wire.

Example 7. A 2000-foot copper line wire is 0.204 inch in diameter. What is the voltage drop in sending 40 amperes through it?

$$\begin{aligned}\text{Resistance} &= \frac{\text{resistance of unit wire} \times \text{length}}{\text{circular mils}} \\ &= \frac{10.4 \times 2000}{204 \times 204} \\ &= 0.5 \text{ ohm.} \\ \text{Volts} &= \text{ohms} \times \text{amperes} \\ &= 0.5 \times 40 \\ &= 20 \text{ volts.}\end{aligned}$$

Prob. 38-5. How many volts are required to send 3 amperes through 400 feet of copper wire 0.064 inch in diameter?

Prob. 39-5. What voltage is required to send 20 amperes through 1000 feet of copper wire 0.162 inch in diameter?

Prob. 40-5. A $\frac{1}{4}$-inch copper wire carries 50 amperes. What is the voltage drop per mile?

Prob. 41-5. A copper wire carries 120 amperes for 2500 feet. If its diameter is 0.364 inch, what is the voltage drop?

Prob. 42-5. How many amperes can be forced through 1500 feet of copper wire $\frac{1}{8}$ inch in diameter, with a voltage drop of 5 volts?

Prob. 43-5. What size copper wire must be used if 6 volts are to be used in forcing 25 amperes through 1 mile of wire?

Prob. 44-5. If 12 volts are used in forcing 30 amperes through a line wire $\frac{3}{16}$ inch in diameter, what is the length of the wire?

FIG. 93. There is a drop in pressure along the line wires between generator *G* and motor *M*.

Prob. 45-5. The motor, Fig. 93, is 250 feet from the generator and requires 18 amperes. What size line wire must be used?

Prob. 46–5. How far will a pair of copper line wires transmit 25 amperes with a line drop of 8 volts, if the wire is 0.262 inch in diameter?

Prob. 47–5. Each arc lamp, Fig. 94, takes 4 amperes at 85 volts. The distance between lamps is 200 feet. The lamps nearest the generator are 200 feet from it. What size wire is used for line wires?

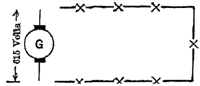

Fig. 94. There is a voltage drop along the wires connecting the lamps.

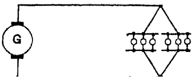

Fig. 95. The voltage at the generator must be higher than the voltage at the lamps.

Prob. 48–5. Each lamp in Fig. 95 takes 1 ampere at 115 volts. The lamps are 500 feet from the generator. The line wire is $\frac{1}{8}$ inch in diameter. What is the voltage of the generator?

Prob. 49–5. A copper wire is 500 feet long and 0.229 inch in diameter. How many volts will it take to send 15 amperes through it?

Prob. 50–5. What will be the drop per mile in a line consisting of copper wire $\frac{1}{10}$ inch in diameter carrying 20 amperes?

Prob. 51–5. What will be the line drop in voltage and loss in watts per mile in transmitting 12 kilowatts at 550 volts, if a copper wire is used having a diameter of 0.162 inch?

Prob. 52–5. A group of incandescent lamps takes 12 amperes. The line drop is not to exceed 3.3 volts. What must be the size of the copper wire to be used if the lamps are 2500 feet from the generator?

Prob. 53–5. A 220-volt, 25-horse-power motor of 88 per cent efficiency is situated 500 feet from the generator. Copper wire 0.460 inch in diameter is used for the line. What must be the voltage of the generator?

Prob. 54–5. What size wire might have been used in Prob. 53–5 if a line drop of 3 per cent of the voltage of the generator had been desired?

Prob. 55–5. What size of copper wire is required between a 115-volt generator and a 110-volt 10-horse-power motor of 85 per cent efficiency? The motor and generator are 1800 feet apart.

Prob. 56–5. What power is lost in a mile line if the wire is 0.204 inch in diameter and carries 24 amperes?

Prob. 57–5. A building situated 2200 feet from a 115-volt generator is to be supplied with sufficient current from the generator to light 400 lamps in multiple, each taking 0.25 ampere. Four per cent of the power generated is lost in the line wires. What size copper wire must be used?

43. Copper Wire Table. Wire manufacturers make up certain sizes only of copper wire. These sizes are arranged according to a scale called a Wire Gage. In this country the American Wire Gage (A. W. G.) also called the Brown & Sharpe (B. & S.) Gage is the standard. If any size other than a standard gage is demanded, some manufacturers will make it, though at an increased cost.

The standard sizes are listed in a table (see Table I in Appendix) as follows: The first column contains the gage numbers, of which the even numbers only are in general use except in the very small sizes. The second column shows the diameter in mils of each gage number. The third gives the end area in circular mils, which we have seen is the square of the diameter in mils. The fourth gives the resistance per thousand feet, and the fifth the weight in pounds per thousand feet.

The use of these tables greatly simplifies all wire computations.

Example 8. It is required to find the resistance of 4000 feet of copper wire 0.144 inch in diameter.

By use of the table, No. 7 wire is seen to have a diameter of practically 144 mils and a resistance of 0.497 ohm per 1000 feet.

$$\text{Resistance of 4000 feet} = 4 \times 0.497 = 1.988 \text{ ohms.}$$

Example 9. What size copper wire would be used if 1600 feet of it is to have not more than 0.4 ohm?

$$\text{Resistance per 1000 feet} = \frac{0.4}{1.6} = 0.25 \text{ ohm.}$$

From the table, No. 4 wire with a diameter of 204 mils has a resistance of 0.248 ohm per 1000 feet and is thus the wire required.

NOTE. When the computation demands a wire of a size not in the table, always choose the size next LARGER, that is, one having a SMALLER resistance than that computed. In all problems, copper wire will be assumed unless another material is specified.

Example 10. It is necessary to transmit 4 kilowatts at 230 volts, a distance of 1 mile with a drop of 10 volts. What size wire is required?

Amperes to be transmitted:

$$\text{Amperes} = \frac{\text{watts}}{\text{volts}}$$
$$= \frac{4000}{230} = 17.4 \text{ amperes.}$$

Resistance of line:

$$\text{Resistance (line)} = \frac{\text{volts (line)}}{\text{amperes (line)}}$$
$$\frac{10}{17.4} = 0.574 \text{ ohm.}$$

A 1-mile line would have 2 wires, each 1 mile long, or 2 miles of wire in all.

Resistance of 2 miles, or 10,560 feet = 0.574 ohm.

$$\text{Resistance per 1000 feet} = \frac{0.574}{10.56} = 0.0544 \text{ ohm.}$$

By Table I, No. 0000 has a resistance of 0.0489 ohm per 1000 ft., and No. 000 has a resistance of 0.0617 ohm per 1000 feet.

Thus we would have to use No. 0000 with a diameter of 460 mils.

Prob. 58–5. What size, B. & S. gage, is the wire in Prob. 49–5?

Prob. 59–5. What size, B. & S. gage, is the wire in Prob. 51–5?

Prob. 60–5. What size, B. & S. gage, is the wire in Prob. 53–5?

Prob. 61–5. What size, B. & S. gage, is the wire in Prob. 56–5?

Prob. 62–5. What size (A. W. G.) is a wire having a cross-section of 0.083 sq. in.?

Prob. 63–5. What size copper wire must be used to transmit 30 amperes from a generator to lamps, a distance of 800 feet, with 3 volts line drop?

Prob. 64–5. What is the resistance per mile of No. 10 wire, A. W. G.?

Prob. 65–5. How far can 20 amperes be transmitted through a No. 6 wire, A. W. G., with 2 volts line drop?

Prob. 66–5. What wire (A. W. G.) has a resistance of about 3 ohms per mile?

Prob. 67–5. How many miles of No. 00 wire will it take to make 6 ohms resistance?

Prob. 68–5. In Fig. 56 the lamps are approximately 1000 feet from the generator. What size wire is used?

Prob. 69–5. What is the length of wire in Fig. 57, if No. 12 A. W. G. is used?

Prob. 70–5. If No. 10 wire, B. & S., were used in Prob. 69–5, what would the length of the line be?

Prob. 71–5. No. 12 B. & S. gage is used for line wire in Fig. 88. How far is it from the generator to the lamps?

Prob. 72–5. What size wire is used in Fig. 33 if the motor is 550 feet from the generator?

Prob. 73–5. How many feet of No. 00 wire does it take to make 1 ohm?

Prob. 74–5. What size wire, B. & S., would you use to transmit 50 amperes a distance of 800 feet with 6 volts line drop?

Prob. 75–5. Each lamp, Fig. 96, is a 110-volt, 60-watt lamp. If the lamps are 800 feet from the generator, what size wire, B. & S., must be used?

FIG. 96. The voltage at the lamps is lower than the voltage at the generator.

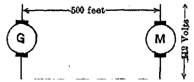

FIG. 97. The difference in voltage between generator and motor is the drop through 1000 ft. of wire.

Prob. 76–5. The motor in Fig. 97 is 5-horse-power, 85 per cent efficiency. The line wires are No. 6.

(*a*) What must be the voltage of the generator?

(*b*) What kilowatt capacity must the generator have?

Prob. 77–5. In Fig. 65, Group I is 300 feet from the generator; Group II is 480 feet from Group I. The generator has 115 volts across its brushes. The wire used in each case is No. 10. What is the voltage across Group I, and across Group II?

Prob. 78–5. If the distances in Prob. 77–5 were twice as great, what size wire could be used for the same voltages across all points?

Prob. 79–5. In Prob. 17–3, No. 0 trolley wire is used. How far are the cars apart?

Prob. 80–5. A coil of No. 20 wire is found to have a resistance of 15 ohms. How many feet are there in the coil?

Prob. 81–5. A coil for an electromagnet has 800 turns of No. 23, B. & S. copper wire. The average length of a turn is 6 inches. What is the resistance of the coil?

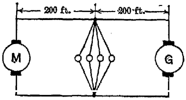

FIG. 98. The voltages at generator, lamps and motor will all be different.

Prob. 82–5. It is desired to construct a coil of not more than 53 ohms resistance. The coil must have 200 turns of about 16 inches average length. What size wire, B. & S., should be used?

Prob. 83–5. Each lamp, Fig. 98, takes 2 amperes at 112 volts. The motor is 110-volt, 4-horse-power, 80

per cent efficiency. What size wire must be used between the motor and lamps?

Prob. 84–5. If No. 4 wire is used between the lamps and generator, what is the voltage of the generator in Prob. 83–5?

Prob. 85–5. What power is lost in the line in Probs. 83–5 and 84–5?

44. Stranded Wire. On account of their greater flexibility, stranded cables are very often used instead of solid wire. Such cables are much easier to pull into conduit, and less likely to break when bent at a sharp angle. Special extra flexible cables are used for train connectors, port-

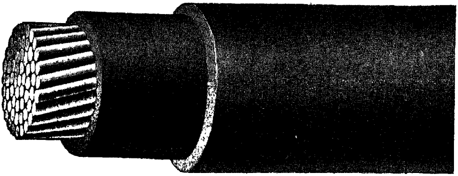

FIG. 99. A lead-covered power cable. Count the number of strands in the successive layers. *American Steel and Wire Co.*

able motor leads, motor or generator brush-holder leads and other similar purposes. Large conductors, especially those larger than No. 0000 are made in strands.

For instance, instead of using a solid No. 4 wire, having a diameter of 204 mils and an area of 41,700 circular mils, it is sometimes more desirable to use a cable made up of 7 wires, each 77.3 mils in diameter and having an area of 77.3 × 77.3 = 5970 circular mils. But since the cable is made up of seven of these strands, the area of the cable is 7 × 5970 = 41,800 circular mils, which is practically the area of a No. 4 solid wire. Or, a No. 4 cable designed for extra flexibility has 49 No. 21 gage wires arranged 7 in a strand with the seven strands twisted together.

On account of the geometry of the cross-section (see Fig. 99) cables are usually made with 7, 19, 37, 61, etc., strands. Successive layers are spiraled in alternate directions.

Prob. 86–5. To what size wire, A. W. G., is a stranded cable equivalent which is made up of 19 strands each 0.051 inch diameter?

Prob. 87–5. It is desired to make a cable of 19 strands which shall be equivalent to a No. 00 A. W. G. solid conductor. What size strands should be used?

Prob. 88–5. Is the very flexible 49-conductor cable described in this section the equivalent of a No. 4 solid conductor?

Prob. 89–5. A certain flexible cable designed for transformer and brush-holder leads has 275 No. 24 copper wires. What size A. W. G. is its nearest equivalent?

Prob. 90–5. (*a*) How many conductors and what arrangement would be used to come nearest to the equivalent of a No. 6 conductor using No. 23 wires?
(*b*) Using No. 24 wires?

45. Aluminum Wire, Iron Wire, etc. Aluminum is being used extensively in the manufacture of conductors for high-tension power transmission. Although its resistance per mil-foot is 17.1 or about 1.64 times that of copper, its density is only 0.3 that of copper. These facts indicate that an aluminum conductor having the same resistance as that of a given copper conductor will be much lighter. For example, a No. 0 (105,530 circular mils) solid copper conductor has a resistance of 0.04893 ohm per 1000 feet. An aluminum conductor having the same resistance would have to have a cross-sectional area of $1.64 \times 105{,}530 = 173{,}200$ circular mils. Its weight would be only $1.64 \times 0.3 = 0.49$ or about one-half that of the copper conductor.

Example 11. What is the resistance of a No. 6 aluminum wire 2000 feet long?

Circular mil area of No. 6 wire = 26,250 circular mils.
Resistance of 1 mil-foot of aluminum = 17.1 ohms.

Resistance of 1 foot of No. 6 aluminum wire $= \frac{17.1}{26{,}250} =$ 0.000651 ohm.

Resistance of 2000 feet of No. 6 aluminum wire $= 2000 \times 0.000651 = 1.302$ ohms, or

$$\text{Resistance} = \frac{\text{resistance of unit wire} \times \text{length}}{\text{circular mil area}}$$

$$\frac{17.1 \times 2000}{26{,}250} = 1.302 \text{ ohms.}$$

The most popular type of aluminum conductor has one or more steel strands at its center to give it additional tensile strength. This combination of lightness and high tensile strength provides an excellent conductor for bridging long spans such as those encountered in river crossings or in mountainous regions. This cable is called aluminum cable steel reinforced (A. C. S. R.).

Iron or steel wire is sometimes used for heating purposes and for resistors but is likely to oxidize and become brittle. It is also used in some kinds of circuits in which very little current is transmitted, such as telephone, telegraph, and signal circuits.

Wires in resistor units are usually made of high-resistance alloys, the resistances of these alloys ranging from 100 to 720 ohms per mil-foot as shown in Table II in the Appendix. Some of these alloys do not change their resistance with changes of temperature and are therefore useful in the manufacture of certain electrical measuring instruments.

Prob. 91–5. What resistance will 1 mile of No. 2 solid copper wire have?

Prob. 92–5. If the wire of Prob. 91–5 were of aluminum, what would its resistance be?

Prob. 93–5. If the wire of Prob. 91–5 were of iron, what would its resistance be? This iron is to have a resistance of 75 ohms per mil-foot.

Prob. 94–5. A No. 0000 all-aluminum cable is composed of 7 strands of 174-mil wires. What is its resistance per 1000 feet and to what size copper conductor is it nearest equivalent?

Prob. 95–5. A No. 0000 cable (A. C. S. R.) is composed of six 188-mil aluminum conductors spiraled around a 188-mil steel core. When used for conducting alternating currents, these currents flow almost exclusively in the aluminum conductors. Neglecting the steel core, what is the resistance of this cable per 1000 feet and to what size copper conductor is it nearest equivalent?

Prob. 96–5. A rheostat is designed to have a resistance of 5 ohms. How many feet of No. 24 nichrome wire will be required?

Prob. 97–5. German silver is an alloy of copper, nickel, and zinc, and is usually listed commercially in terms of its nickel content. What resistance would a 25-foot length of 18 per cent German silver No. 30 wire have?

46. Safe Carrying Capacity for Copper Wires. It is a fact of common experience that an electric current heats the conductor through which it passes.

The filament of an incandescent lamp is made to glow by the heat generated in it. The coils of an electric heater receive their heat from the current passing through them.

We have seen that **resistance** is in reality nothing but **electrical friction.** So, just as a bearing of a machine heats when the machine is running, an electrical conductor heats when a current is running. We decrease the friction of a machine by using smooth surfaces of the proper metals, and then lubricating it, so that the temperature rise is not great enough to do any damage. Similarly, we decrease the resistance of a conductor by choosing a metal of low resistance per mil-foot and making the conductor of large cross-section, so that the temperature rise is not great enough to injure the insulation.

The National Board of Fire Underwriters has issued a table (Table IV of Appendix) for the safe carrying capacity

of copper wire of the sizes usual in house wiring. If a greater current than that indicated is carried by any wire, the insulation is heated, and is likely to melt or take fire. If this current is greatly exceeded, the copper itself is likely to be fused.

Example 12. It is desired to install a conductor to carry 40 amperes. What size copper wire should be used?

From the table, No. 6 rubber-insulated wire will carry 50 amperes, and is the size to be used.

If weatherproof wire can be used, No. 8 will do.

Prob. 98–5. What size rubber-covered wire should be used when it is necessary to carry 15 amperes?

Prob. 99–5. What would be the voltage drop in 200 feet of the wire in Prob. 98–5, when carrying 15 amperes?

47. Relation of Voltage to Watts Lost in the Line. Let us assume that we wish to use eight 110-volt lamps, each taking $\frac{1}{2}$ ampere, as in Fig. 100. The lamps are 2000 feet from the generator and No. 7 wire is used, which makes about 1 ohm per wire.

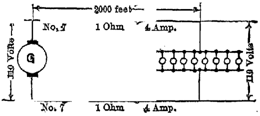

FIG. 100. Two-wire system. The 2 line wires each carry 8 times the current of 1 lamp.

The eight lamps taking $\frac{1}{2}$ ampere each, would take 4 amperes altogether.

To transmit 4 amperes over a 1-ohm wire requires 4 volts. There are two 1-ohm wires, so 8 volts would be required to force the current through the line out to the lamps and back again through the return line.

The power consumed in the line, then, equals

$$\text{volts (used in line)} \times \text{amperes (through line).}$$
$$\text{Watts} = 8 \times 4 = 32 \text{ watts used in line.}$$

The watts used by the lamps equal

volts (across lamps) × amperes (through lamps)
$= 110 \times 4 = 440$ watts used in the lamps.

Thus, in order to get the 440 watts to the lamps we have wasted 32 watts in the line.

Suppose that we now arrange these same lamps as in Fig. 101. By placing two in series in each case, each lamp can get its $\frac{1}{2}$ ampere, and by making the voltage across the two lamps 220 volts, each lamp has 110 volts pressure.

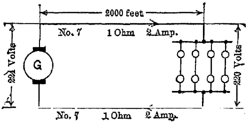

FIG. 101. Two-wire system. The 2 line wires each carry 4 times the current of 1 lamp.

So we really have but 4 parallel circuits each carrying $\frac{1}{2}$ ampere. Thus the 4 circuits carry

$$4 \times \tfrac{1}{2} = 2 \text{ amperes.}$$

The line, then, has to carry only 2 amperes and being the same wire as in Fig. 100 has a total resistance of 2 ohms.

The voltage required to send 2 amperes through 2 ohms is 4 volts. Thus the voltage drop in the line is 4 volts. The power loss in the line wires equals

volts (lost in line) × amperes (through line),

or

$$4 \times 2 = 8 \text{ watts.}$$

Power consumed by the lamps equals

volts (across lamps) × amperes (through lamps),

or

$$220 \times 2 = 440 \text{ watts.}$$

Thus we have transmitted the same power to the same lamps at 220 volts with only 8 watts loss against the 32 watts loss where 110 volts were used.

Note that doubling the voltage makes the line loss one-quarter as great. Thus, if we are to transmit at 220 volts,

we can make use of the great advantage gained over 110 volts in either of two ways.

(1) We may use the same line wires as we would for 110 volts, and save operating expenses by taking advantage of the small line loss. The first cost of the outfit would be the same as the 110-volt transmission.

(2) Or we might wish to lessen the first cost of the outfit and allow operating expenses to be the same as for the 110-volt transmission. We would be enabled to do this by using a smaller copper wire. In fact, we might use wire having only one-quarter the area and still have the same line loss as in a 110-volt line transmitting the same power.

Thus, making use of this second advantage, we might use a No. 13 instead of a No. 7 wire. The line resistance would then become 4 ohms per wire or a total of 8 ohms for the line.

It would require 8 × 2, or 16 volts to send the 2 amperes of Fig. 101 through this line.

The line loss would then become

$$16 \text{ (volts)} \times 2 \text{ (amperes)} = 32 \text{ watts,}$$

which is the same as in the 110-volt line of Fig. 100, which used 4 times as large a wire.

It is clear, then, that in transmitting at 220 volts, a great saving can be made either in operating expenses or in the first cost of installation.

So we could use a No. 13 wire which has only one-quarter the area of a No. 7, thus weighs only one-quarter as much, and costs only about one-quarter as much.

48. Three-Wire System. This great saving of power or copper in the line by merely doubling the voltage has led to the wide establishment of 220-volt circuits. But lamps of about 110-volt rating are the most common type of incandescent lamp because they are the cheapest and most durable, and if they are to be used on a 220-volt circuit,

they must be put two in series. This would compel a customer always to burn at least two lamps at once. If he needed three lamps, he would have to use four, two parallel sets of two in series.

To avoid this bad feature and still retain the advantage of transmitting at 220 volts, a third wire, called a **neutral**, has been added to the arrangement in Fig. 101, which produces the **three-wire system**, as shown in Fig. 102.

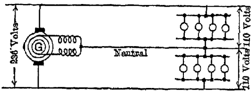

FIG. 102. Three-wire system. Each outside wire carries 4 times the current of 1 lamp. The neutral carries no current in this case.

This neutral wire is usually the same size as each of the other two. So if we allow the same watts lost in the line, the total amount of copper is a little greater than one-quarter that of the two-wire system of Fig. 102. In fact, there is just three-eighths as much copper in the three-wire system.

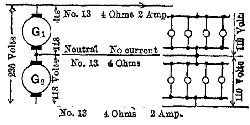

FIG. 103. Three-wire system; balanced. Neutral carries no current.

The generator also has to have a special device to which this third wire is attached. It is much simpler, however, to consider the generator as divided into two 110-volt generators in series as in Fig. 103, with the neutral coming to the junction of the two.

49. Balanced and Unbalanced Three-Wire System. When there are the same number of lamps burning on each side of the neutral, as in Fig. 103, the neutral carries no current, and the system is said to be **balanced**. It is only when the system is **unbalanced** that the neutral is of use and carries current, as in Fig. 104. The system may be said

to be unbalanced, then, when the appliances on one side of the neutral are carrying more current than those on the other side, thus compelling the neutral to carry the surplus. Thus, if four $\frac{1}{2}$-ampere lamps were turned on, as in Fig. 104, on the (+) side of the neutral, and only one on the other side, the neutral would have to carry $1\frac{1}{2}$ amperes back to the generator G_1 which is supplying the greater part of the power. If, however, the four $\frac{1}{2}$-ampere lamps had been turned on, as in Fig. 107, on the (−) side of the neutral, and only one on the (+) side, then since the (+) side is supplying only $\frac{1}{2}$ ampere, the neutral must carry $1\frac{1}{2}$ amperes from the generator out to the lamps. G_2 is now supplying most of the power.

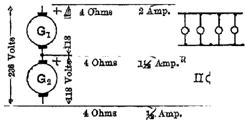

FIG. 104. Three-wire system; unbalanced. Neutral carries some current.

50. Voltage Distribution in Three-Wire System. In using the three-wire system, every effort is made to keep it balanced. In this case, the voltage, current and power distribution differ in no respect from that of a two-wire system, with lamps, or other electrical appliances, paired off, two in series, as in Fig. 101.

Of course on a large system any slight deviation from a balance makes no noticeable difference, but it is instructive to see what happens to the voltage distribution in a system unbalanced as much as that of Fig. 104.

The voltage across Group I is very easy to find.

To force 2 amperes through the line out to the lamps over a 4-ohm wire requires

$$2 \times 4 = 8 \text{ volts.}$$

To force $1\frac{1}{2}$ amperes through the return line to the generator over a 4-ohm wire (the neutral) requires

$$1\tfrac{1}{2} \times 4 = 6 \text{ volts.}$$
$$\text{Line drop} = 6 + 8 = 14 \text{ volts.}$$
$$\begin{aligned}\text{Voltage across Group I} &= \text{voltage of } G_1 - (\text{line drop}) \\ &= 118 - 14 = 104 \text{ volts.}\end{aligned}$$
$$\text{Voltage across Group I} = 104 \text{ volts.}$$

The voltage across Group II is a little more difficult to compute. The easiest way is to draw a "voltage diagram," as in Fig. 105 and 106. Fig. 105 represents the voltage diagram of the circuit for Group I.

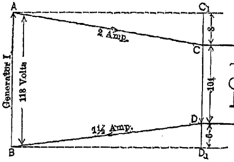

FIG. 105. Voltage diagram for upper part of Fig. 104.

Let the vertical line AB represent the 118 volts of the generator. Then draw the line wire AC sloping in the direction in which the current flows. Since the voltage drops 8 volts along the top wire, the line AC falls 8 from the level of A. In the same way the line DB slopes in the direction in which the current flows and falls 6 from the level of D, representing the 6 volts lost in the neutral wire. The rest of the vertical distance, from the level of A to the level of B, is the voltage across the points C and D, where the lamps of Group I are located. This is 104 volts, which agrees with the result found by computation.

Another way of stating it is that the distance between the horizontal lines is the voltage of the generator. Thus the line C_1D_1 would represent 118 volts. The line CD is 14 shorter than C_1D_1 and therefore represents 104 volts,

which is the voltage across the lamps, because they are across the points C and D.

If, now, we should consider the circuit of Group II in the same way we would draw Fig. 106. The vertical line BE represents the voltage across G_2. BD is the neutral sloping toward the generator as drawn in Fig. 105, representing a fall of 6 volts toward the generator as a current is flowing

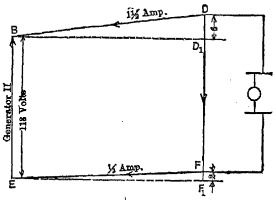

FIG. 106. Voltage diagram for lower part of Fig. 104.

in this direction. Line FE represents the wire EF in which a current of $\frac{1}{2}$ ampere is flowing to generator II. Therefore the line FE slopes toward the generator. Since the wire FE has a resistance of 4 ohms, it requires $\frac{1}{2} \times 4$, or 2 volts to force the $\frac{1}{2}$ ampere through it. Therefore the line FE falls 2 points from the level of F. Group II is connected to the line at points D and F, thus DF must represent the voltage across Group II. The distance between the horizontals is always the same as the voltage of the generator. The line D_1F_1, therefore, represents 118 volts. But the line DF, which represents voltage across Group II, is 2 shorter than D_1F_1 at one end, but 6 longer at the other; thus it must be in all, 4 longer. It therefore represents $118 + 4$ volts, or 122 volts. Since Group II is connected in at points D and F, it must have 122 volts across it. Thus the voltage across Group II is 122 volts.

The voltage across Group I was found to be only 104 volts.

The lamps of both groups were made to run on 110 volts as in Fig. 103, and would have their life shortened by 122 volts. We can say, then, that the result of extreme unbalancing is so greatly to disturb the voltage distribution, that appliances built for special voltages would not operate satisfactorily on the system.

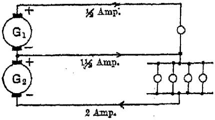

Fig. 107. Three-wire system; unbalanced. Neutral carries some current.

Prob. 100–5. If there were 6 lamps in Group I and 2 lamps in Group II, Fig. 104, each taking $\frac{1}{2}$ ampere, other things remaining unchanged, what would the voltage across each group become?

Prob. 101–5. What is the voltage distribution in Fig. 107, if the wires have a resistance of $2\frac{1}{2}$ ohms each? The generators maintain 115 volts each and each lamp takes 0.50 ampere.

51. Broken Neutral in a Three-Wire System. One other danger in a three-wire system is the chance that the neutral may become broken at the same time that the load is unbalanced. This is not at all a common occurrence, but it is interesting to see what happens when it does take place.

Consider the neutral in Fig. 104 broken at (x). We should then have a series circuit as in Fig. 108.

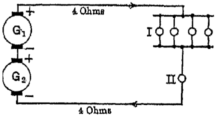

Fig. 108. Effect of broken neutral in three-wire system of Fig. 104.

In order to get at the approximate value of the current that would flow, we will assume that the resistance of each lamp remains about 220 ohms.

Combined resistance of Group I	= $\frac{1}{4}$ of 220	=	55	ohms.
" " " Group II	=		220	"
" " " line	= 4 + 4	=	8	"
	Total resistance	=	283	ohms.

$$\text{Total current} = \frac{\text{(total) voltage}}{\text{(total) resistance}}$$
$$= \frac{236}{283} = 0.834 \text{ ampere.}$$

Voltage across Group I.

Volts (across lamps) =
amperes (through lamps) × ohms (of lamps)
$= 0.834 \times 55$
$= 45.8$ volts.

Voltage across Group II.

Volts (across lamps) =
amperes (through lamps) × ohms (of lamps)
$= 0.834 \times 220$
$= 183.5$ volts.

Thus lamps in Group I would not glow, while lamps in Group II would soon burn out, all lamps being made for 110 volts.

Prob. 102–5. Find the distribution of voltage if the neutral in Prob. 100–5 broke.

Prob. 103–5. Find the voltage distribution if the neutral in Prob. 101–5 broke.

Prob. 104–5. Find the voltage distribution if the neutral in Fig. 103 broke.

SUMMARY OF CHAPTER V

Wire is usually made of copper or aluminum on account of their low resistance.

The resistance of one foot of any size wire being known, the resistance of any length is found by multiplying by the length in feet.

The resistance of one foot of wire $\frac{1}{1000}$ inch in diameter being known, the resistance of one foot of wire of any diameter can be found by dividing by the square of the diameter in thousandths of an inch.

A MIL is $\frac{1}{1000}$ inch.

A CIRCULAR MIL is the area of a circle one mil in diameter.

The area of any circle in circular mils equals the square of the diameter in mils.

A UNIT WIRE is called a mil-foot, and is a round wire one foot long and one mil in diameter.

The resistance of a mil-foot of copper wire is 10.4 ohms.

The resistance of a round copper wire equals

$$\frac{10.4 \text{ (resistance of mil-foot)} \times \text{length in feet}}{\text{circular mil area}}.$$

The resistance of standard sizes of copper wire may be found from wire tables.

Wire is often stranded for greater flexibility. The gage number of stranded wire depends upon the total circular mil area of all the strands and is equivalent to a solid wire of the same area.

The resistance of a mil-foot of aluminum wire is 17.1 ohms.

The resistance of a mil-foot of iron wire varies from 60 to 90 ohms.

The resistance of a mil-foot of alloys, such as manganin, German silver, etc., may be as high as 720 ohms.

For interior wiring, the Underwriters will not insure a house where the wires carry more than the current indicated in the table, "Safe Carrying Capacity of Copper Wires." This is because of the heating effect of the current.

The same amount of power can be transmitted over the same wires at $\frac{1}{4}$ the line loss in watts if 220 volts are used instead of 110 volts.

The same amount of power can be transmitted at the same loss in watts over wires of $\frac{1}{4}$ the weight (or area) if 220 instead of 110 volts be used.

To secure either of these advantages and still not prevent the use of 110-volt appliances, the THREE-WIRE system has been invented.

The NEUTRAL carries current only in case one line wire is carrying more current than the other. This is called an UNBALANCED CIRCUIT and results in an uneven distribution of the voltage. A broken neutral with an unbalanced load may ruin appliances attached to the line.

PROBLEMS ON CHAPTER V

Prob. 105–5. How many 110-volt lamps, each taking 0.25 ampere, can be put on a circuit where the watts are not to exceed 660?

Prob. 106–5. What size wire must be used for the conductor in Prob. 105–5?

Prob. 107–5. What will be the voltage drop along 300 feet of No. 14 wire, when it is loaded as in Prob. 105–5?

Prob. 108–5. Seven No. 31 copper wires are stranded into a cable. To what size (B. & S.) gage is the cable equivalent?

Prob. 109–5. How many strands of No. 10 wire should be in a cable which is equivalent to a No. 6 solid wire?

Prob. 110–5. How many strands of No. 32 wire will it take to make a cable equivalent to a No. 5 solid wire?

Prob. 111–5. What is the diameter of a solid wire having 250,000 circular mils area?

Prob. 112–5. How many No. 18 strands will it take to make a cable equivalent to the solid wire of Prob. 111–5?

Prob. 113–5. What would be the carrying capacity of the wire in Prob. 111–5?

Prob. 114–5. What is the safe carrying capacity of the cable in Prob. 108–5?

Prob. 115–5. What size aluminum wire is equivalent in resistance to No. 10 copper wire?

Prob. 116–5. What would be the approximate safe carrying capacity of the aluminum wire in Prob. 115–5 if rubber covered?

Prob. 117–5. Assume that each lamp in Fig. 109 takes 1.5 amperes, and that the resistance of the lamps remains constant. The brush potential of each generator is 112 volts. Find

(*a*) The line drop in each section.

(*b*) The voltage across each set of lamps.

(*c*) The power delivered by G_1 and by G_2.

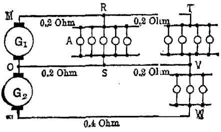

FIG. 109. Three-wire system. More complicated grouping.

Prob. 118–5. If a break should occur in the neutral between O and S, what would be the values of (*a*), (*b*) and (*c*), Prob. 117–5?

Prob. 119–5. If a break should occur in the neutral between S and V, what would be the values of (*a*), (*b*) and (*c*), Prob. 117–5?

Prob. 120–5. It is desired to deliver 150 horse power at a pressure of 550 volts to a point 2 miles from the generator. The watts lost in the line are not to exceed 7 per cent of the watts delivered. What size copper wire should be used?

Prob. 121–5. What size aluminum wire should be used in Prob. 120–5?

Prob. 122–5. What size copper wire should be used to convey current to a group of 200 lamps, each rated at 110 volts, 100 watts? The generator maintains a pressure of 118 volts and is 800 feet from the lamps.

Prob. 123–5. Allowing 2 per cent increase in resistance due to stranding, what is the resistance per 1000 feet of a hard-drawn copper cable composed of 37 strands of 116.2-mil wire? Hard-drawn copper has a resistance of 10.7 ohms per mil-foot at 68° F.

Prob. 124–5. What is the resistance per 1000 feet of an all-aluminum cable made up like the copper cable of Prob. 123–5?

Prob. 125–5. What is the resistance per 1000 feet of an all-aluminum cable made up of nineteen 162.3-mil conductors?

Prob. 126–5. On very hot days the temperature of aerial transmission-line conductors runs over 100° F. When the temperature is 122° F., the resistance of hard-drawn copper is 12.2 ohms per mil-foot. Find the change in resistance when the temperature of the cable of Prob. 123–5 changes from 68° F. to 122° F.

Prob. 127–5. Find the rise in the resistance of the cable of Prob. 124–5 as the temperature rises from 68° F. to 122° F. if the resistance of commercial aluminum at 122° F. is 19.4 ohms per mil-foot. What per cent change is this?

Prob. 128–5. Find the resistance of 1 mile of 500,000 circular mil cable (A. C. S. R.) composed of thirty 129.1-mil aluminum strands and 7 steel strands. Neglect the resistance of the steel core.

Prob. 129–5. Copper-clad steel wire made by the molten welding process is being used for telephone transmission lines on account of its higher tensile strength than that of copper wire. A No. 4 conductor of this type has a resistance of 0.636 ohm per 1000 feet. (*a*) Compare this with the resistance of a copper wire of the same size. (*b*) Compare with the resistance of an aluminum wire of the same size. (*c*) Compare with the resistance of an "Extra Best Best" (E. B. B.) galvanized iron wire.

Prob. 130–5. What would be the ratio of sizes of copper-clad steel, copper, aluminum, and E. B. B. wires of the same resistance per 1000 feet?

Prob. 131–5. (*a*) How many feet of No. 18 Calorite resistance wire will be required to make a 10-ohm resistor?

(*b*) How many feet of 30 per cent German silver wire, No. 18, would it take?

CHAPTER VI

BATTERIES

52. Generators versus Batteries. There are two ways of generating electric pressure commercially.

One method is by moving the wires wound on an armature core in the strong magnetic field of the poles. Machines built on this principle are called **electric generators.**

The other way is by chemical action. Devices using this principle are called **electric batteries.**

When electric power is to be generated in large quantities, the generator is used. When small quantities of power are to be generated for such purposes as ringing bells, actuating signaling devices, lighting small lamps and furnishing power for vacuum-tube circuits in small radio receiving sets, batteries are more convenient and economical. Storage batteries are used as standby power supply in central telephone plants and in small lighting sets, and are "floated" on trolley systems to equalize the voltages. We are all aware of the importance of the storage battery in the operation of automobiles and observe that a small per cent of city vehicles are completely propelled by power from these storage batteries.

53. Electromotive Force. It has been found that if we put two electrical conductors, such as a zinc plate and a copper plate, into a weak solution of some acid, such as sulphuric, so that they do not touch each other, an electric pressure is set up between the plates. The copper plate becomes (+) and the zinc (−), so that when the plates are joined by a wire a current flows from the copper to the zinc. The electric pressure thus set up is called the **electromotive force** and is measured in volts. It is really the electric **moving**

force, which moves the current through the circuit. The letters "e.m.f." are generally used instead of the words "electromotive force."

The e.m.f., then, is the voltage across the terminals of the cell when it is not delivering current, hence it is sometimes called the "open-circuit voltage." To find the electromotive force, or open-circuit voltage, of a cell, it is necessary merely to place a low reading voltmeter across the terminals when the cell is not delivering current.

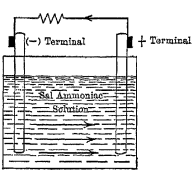

FIG. 110. Simple primary cell sending current through a circuit.

Almost any two electrical conductors might be used for plates instead of zinc and copper, the only requirement being that the two must not be the same material. Likewise other liquids might be used in the place of the sulphuric acid, the requirement here being that the liquid must attack one of the metals chemically.

The e.m.f. set up depends entirely upon what plates and chemical are used. The size of the plates makes absolutely no difference. A large battery cell of the same materials gives exactly the same e.m.f. as a small one.

The e.m.f.'s of cells using different plate materials and electrolytes are given in the following table:

- Plate	*Electrolyte*	*+ Plate*	*Initial e.m.f.*
Zinc	Sulphuric Acid	Copper	1 volt
"	{ Zinc Sulphate Copper Sulphate }	"	1.07 volts
"	Caustic Soda	Copper Oxide	0.90 volt
"	Sal Ammoniac	Carbon	1.5 volts
"	Chromic Acid	"	2 volts
Lead	Sulphuric Acid	Lead Peroxide	2 volts
Nickel	Caustic Potash	Iron	1.20 volts

It should be noted that when a cell is discharging, the current flows from the (+) plate to the (−) plate in the external circuit, but from the (−) plate to the (+) plate within the cell through the electrolyte. See Fig. 110.

54. Types of Cells. Certain cells are designed to be used as long as chemical action continues efficiently, and then they are either thrown away or the (−) plates and electrolytes renewed. Such cells are called primary cells as distinguished from those designed to be restored to their original chemical state by passing a reversed electric current through them. These latter are called secondary or storage batteries.

Of the primary cells there are two types, wet and dry. The zinc-carbon-sal-ammoniac cell may be made up in a glass jar with the electrodes (plates) immersed in a solution of sal-ammoniac or it may be made up in a zinc can with the carbon electrode held rigidly in place by a plaster paste containing the water solution of sal-ammoniac. Some other chemicals are added to this latter type to absorb the gases given off when chemical action takes place and the can is sealed at the top with a compound resembling sealing wax. On account of the greater convenience and low cost, this latter or dry type of construction has almost entirely replaced the former or wet type. Of course dry cells are not really dry, but the fluid is held by the plaster so that it will not run out, much as ink is held by blotting paper. In both cases the zinc is eaten away by the sal-ammoniac, changing the electrolyte into a different and ineffective chemical compound.

55. Internal Resistance. Although the two cells just mentioned have the same e.m.f., they are very different in another respect. The resistance of the path through the liquid, from the zinc to the carbon, is very high in the wet battery, being between 0.5 and 4 ohms. This is called the

internal resistance of the cell. In the case of a good dry cell, it is usually less than 0.1 ohm.

Since some of the e.m.f. of the cell must always be used up in sending a current through this internal resistance, it is essential that it should be as low as possible, especially when the battery is to deliver much current.

56. Current Delivered by Cell. Of course the amount of current delivered by a cell obeys Ohm's law absolutely, and depends upon the e.m.f. of the cell and the resistance of the entire circuit.

Now a cell has a certain available voltage, that is, the e.m.f., with which to send a current through the two parts of a circuit, which consist of the part outside the cell and the part inside the cell. The strength of the current depends, then, upon how great the resistance of these two parts is. The current is always equal to the e.m.f. divided by the sum of these two resistances. That is,

$$\text{(total) current} = \frac{\text{(total) voltage}}{\text{(total) resistance}}.$$

In this case,

$$\text{(total) current} = \frac{\text{e.m.f. (which is total voltage)}}{\text{internal resistance} + \text{outside resistance}}.$$

Example 1. A cell has an e.m.f. of 1.50 volts and an internal resistance of 0.20 ohm. What current will the cell send through a 2.80-ohm wire?

$$\begin{aligned}\text{Current} &= \frac{\text{e.m.f.}}{\text{internal resistance} + \text{outside resistance}}\\ &= \frac{1.50}{0.20 + 2.80}\\ &= \frac{1.50}{3.00} = 0.5 \text{ ampere.}\end{aligned}$$

Example 2. If the cell in Example 1 had an internal resistance of 4 ohms, what current would it send through the same wire?

$$\text{Current} = \frac{\text{e.m.f.}}{\text{internal resistance} + \text{outside resistance}}$$

$$= \frac{1.50}{4 + 2.8}$$

$$= \frac{1.50}{6.80} = 0.221 \text{ ampere.}$$

Note that with the same e.m.f. and the same wire, less than half the current flows in the second example, because the internal resistance is so much higher.

Prob. 1–6. What current will a battery cell of 1.28 volts e.m.f. and 2.4 ohms internal resistance send through a miniature lamp of 12 ohms resistance?

Prob. 2–6. A dry cell has an e.m.f. of 1.51 volts and an internal resistance of 0.07 ohm. What current will it deliver through a 10-ohm wire?

Prob. 3–6. What current will the cell of Prob. 2–6 deliver through a 0.1-ohm wire?

Prob. 4–6. What current will the cell in Prob. 2–6 deliver through a 0.01-ohm wire?

Prob. 5–6. What current will the cell in Prob. 2–6 deliver through a short circuit; that is, a wire of practically no resistance?

Prob. 6–6. A wet cell has the same e.m.f. as the cell in Prob. 2–6, but an internal resistance of 4.5 ohms. What current will this cell deliver through a 10-ohm wire?

Prob. 7–6. What current will the cell in Prob. 6–6 deliver through a short circuit?

Prob. 8–6. What respective currents will the cells in Probs. 2–6 and 6–6 deliver through 100 ohms?

It is well to note in the above problems, that when the external resistance is high, it does not make very much difference with the current whether the internal resistance of the cell is high or low. But if the external circuit has a low resistance, it makes a great difference in the current whether the cell used has a high or a low internal resistance.

57. Terminal Voltage. It is interesting to observe that the small current delivered by a cell of high internal re-

sistance even on short circuit is due to the fact that so much of the e.m.f. of the cell is used up in sending the current through the internal resistance, that but little is left to send the current through the external resistance. The voltage used in sending the current through the internal resistance is, of course, found by Ohm's law, just as is the voltage to send a current through any other kind of resistance.

Example 3. A cell has an internal resistance of 1.2 ohms. How many volts of its e.m.f. are used to send the current through the cell itself when it is delivering 0.5 ampere?

$$\begin{aligned} \text{Voltage} &= \text{current} \times \text{resistance} \\ &= 0.5 \times 1.2 \\ &= 0.60 \text{ volt.} \end{aligned}$$

Example 4. If the cell in Example 3 had an e.m.f. of 1.48 volts, how many volts would it have across the ouside circuit?

It is plain that, if the cell has an e.m.f. of 1.48 volts and uses 0.60 volt of this e.m.f. to send a current through itself, then it can have but 1.48 − 0.60, or 0.88 volt left to send a current through some outside circuit. That is, if we put a voltmeter across the terminals of this cell on open circuit, we should find it had a voltage or an e.m.f. of 1.48 volts. But if we connected a wire across it and allowed 0.5 ampere to flow as in the example, then the voltmeter would read only the 0.88 volt used in sending current through this outside wire. This is called the **terminal voltage** of the cell for a certain current. If it were possible (which it is not) to place a voltmeter across the inside of the cell, we should find that the other 0.60 volt, of the 1.48 volts which the cell has, is used to force the current through the inside of the cell. The whole e.m.f. of 1.48 volts is then used up as follows:

Volts to force current through wire =	0.88 volt.
" " " " cell =	0.60 "
Total voltage or e.m.f.	1.48 volts.

This is true in the case of every cell delivering a current.

To find what terminal voltage a cell will have when sending a given current through a line, we must subtract the drop across the inside of the cell from the e.m.f.

That the terminal voltage of a given cell depends upon what current it is delivering, can be seen from the following examples.

Example 5. A cell of 0.14 ohm internal resistance and 1.5 volts e.m.f. is delivering 10 amperes. What is the terminal voltage?

Volts used in overcoming internal resistance = current $\times$ internal resistance

$$= 0.14 \times 10$$
$$= 1.40 \text{ volts.}$$

Terminal voltage = e.m.f. − volts used on internal resistance

$$= 1.5 - 1.4$$
$$= 0.1 \text{ volt.}$$

Example 6. If the cell of Example 5 is delivering 5 amperes only, what will be its terminal voltage?

Volts used across int. res. = current $\times$ internal resistance

$$= 5 \times 0.14$$
$$= 0.70 \text{ volt.}$$

Terminal voltage = e.m.f. − volts used across internal resistance

$$= 1.50 - 0.70$$
$$= 0.80 \text{ volt.}$$

We see that, by reducing the current to one-half, we greatly increased the terminal voltage. We may say, then, that:

The smaller the current a cell is delivering, the greater its terminal voltage.

Prob. 9–6. What is the terminal voltage of a cell which is delivering 4 amperes if it has an e.m.f. of 1.5 volts and an internal resistance of 0.2 ohm?

Prob. 10–6. Could the cell in Prob. 9–6 deliver 8 amperes? If so, what would be its terminal voltage? If not, why not?

Prob. 11–6. What maximum current could the cell of Prob. 9–6 deliver?

Prob. 12–6. What would be the terminal voltage of the cell in Prob. 9–6 when it was delivering its maximum current?

Prob. 13–6. What would be the terminal voltage of the cell in Prob. 9–6 when delivering no current?

Prob. 14–6. A cell has an internal resistance of 2.1 ohms and an e.m.f. of 1.2 volts. The external circuit has a resistance of 5 ohms.

Find:

(*a*) The current flowing.
(*b*) Voltage drop across the internal resistance.
(*c*) Terminal voltage.

Prob. 15–6. A cell is delivering 3.2 amperes. Its internal resistance is 0.2 ohm, and its e.m.f. is 1.24 volts. What will a voltmeter read if put across the terminals of the cell?

Prob. 16–6. What is the external resistance in Prob. 15–6?

Prob. 17–6. Through what external resistance will a cell deliver 6 amperes if its e.m.f. is 1.4 volts and its internal resistance 0.12 ohm?

Prob. 18–6. The cell in Fig. 111 has an e.m.f. of 1.35 volts. The ammeter reads 0.25 ampere. What is the internal resistance of the cell?

Prob. 19–6. What would a voltmeter read if put across the cell connected as in Fig. 111?

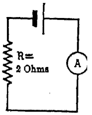

FIG. 111. Ammeter *A* indicates the current delivered by the battery cell.

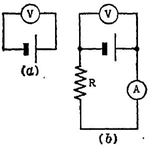

FIG. 112. Two tests are made to determine the internal resistance of the cell.

Prob. 20–6. A voltmeter put across a cell as in Fig. 112 (*a*) reads 1.46 volts. When put across the same cell connected as

in Fig. 112 (*b*) the voltmeter reads 0.92 volt. The ammeter A reads 9 amperes.

Find:

(*a*) The e.m.f. of the cell.
(*b*) Internal resistance of cell.
(*c*) Resistance of R.

58. Best Arrangement of Cells. Suppose that we wish to send as large a current as possible through a telegraph relay which has 100 ohms resistance and have but 8 cells, each of 1.5 volts e.m.f. and 2 ohms internal resistance. How shall we arrange them?

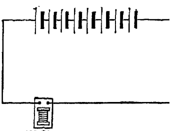

FIG. 113. The 8 cells in series are sending current through the coil.

Suppose that we put them all in series as in Fig. 113. The voltage across a series circuit, we remember, is the sum of the voltages across all the parts; so the e.m.f. of the combination of cells will be the sum of the e.m.f.'s of the cells, or

$$8 \times 1.5 = 12 \text{ volts.}$$

This is the only e.m.f. in the circuit, and is therefore the e.m.f. of the entire circuit.

The resistance of a series circuit is the sum of the resistances of all the parts, or

$$(8 \times 2) + 100 = 116 \text{ ohms.}$$

Current (through entire circuit)

$$= \frac{\text{voltage (across entire circuit)}}{\text{resistance (of entire circuit)}}$$
$$= \tfrac{12}{116}$$
$$= 0.104 \text{ ampere.}$$

Now suppose that we put the cells in parallel as in Fig. 114. Since the voltage across a parallel combination is the same as the voltage across each branch, the combined e.m.f.

of the cells is the same as the e.m.f. of one cell, that is, 1.5 volts.

But the resistance of a parallel combination, made up of equal resistances, is the resistance of one piece divided by the number of pieces; therefore the internal resistance of the 8 cells in parallel, each having 2 ohms internal resistance, is

$$\frac{2}{8} = \frac{1}{4}, \text{ or } 0.25 \text{ ohm.}$$

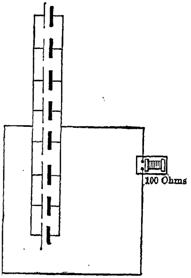

FIG. 114. The cells of Fig. 113 are here arranged in parallel to send current through the coil.

This parallel combination, however, is in series with the 100 ohms of the relay, therefore the entire resistance of the circuit is

$$100 + 0.25, \text{ or } 100.25 \text{ ohms}$$

Current (through entire circuit)

$$= \frac{\text{voltage (across entire circuit)}}{\text{resistance (of entire circuit)}}$$

$$= \frac{1.5}{100.25}$$

$$= 0.0149 \text{ ampere.}$$

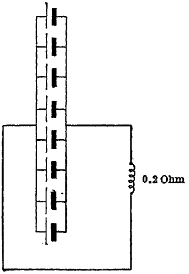

FIG. 115. The 8 cells are in parallel.

The current when the cells were in series was 0.104 ampere, or about 7 times as great as when the cells were in parallel. As a general rule, it may be stated that:

The series arrangement of cells gives the greatest current when the external resistance to be overcome is large.

Suppose, however, that we wanted to use the same cells to send the greatest current possible through a coil of 0.2 ohm

resistance. If we arranged the cells all in parallel, as in Fig. 115, the voltage of the circuit would be the voltage of one cell alone, or 1.5 volts.

The resistance of the cells would be $\frac{2}{8}$, or 0.25 ohm. The resistance of the entire circuit would then be $0.25 + 0.2 = 0.45$ ohm.

Current (through entire circuit)

$$= \frac{\text{voltage (across entire circuit)}}{\text{resistance (of entire circuit)}}$$

$$= \frac{1.5}{0.45} = 3.33 \text{ amperes.}$$

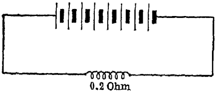

FIG. 116. The 8 cells are in series.

If we arranged the cells all in series, as in Fig. 116, the e.m.f. of series combination of cells would be

$$8 \times 1.5, \text{ or } 12 \text{ volts.}$$

The internal resistance of cells would be 8×2, or 16 ohms. Resistance of entire circuit would be

$$16 + 0.2 = 16.2 \text{ ohms.}$$

Current (through entire circuit)

$$= \frac{\text{voltage (across entire circuit)}}{\text{resistance (of entire circuit)}}$$

$$\frac{12}{16.2} = 0.74 \text{ ampere.}$$

Here the current for the parallel arrangement was 3.33 amperes or about $4\frac{1}{2}$ times as great as the series. This is exactly the opposite of the case where we had 100 ohms for an external resistance instead of 0.2 ohm.

As a general rule, then, it may be stated that:

The parallel combination of cells gives the greatest current when the external resistance is very small.

Suppose again that we wished, with the same batteries, to ring a bell of 4 ohms resistance, which is neither very high nor very low, with the greatest current possible.

If we used them all in series the voltage would be

$$8 \times 1.5, \text{ or } 12 \text{ volts.}$$

The internal resistance of cells would be

$$8 \times 2, \text{ or } 16 \text{ ohms.}$$

The resistance of entire circuit would be

$$16 + 4 = 20 \text{ ohms.}$$

Current (through entire circuit)

$$= \tfrac{12}{20} = 0.6 \text{ ampere.}$$

If we used them all in parallel;

$$\begin{aligned} \text{Voltage of the combination of cells} &= 1.5 \text{ volts.} \\ \text{Internal resistance of cells} &= \tfrac{2}{8} = 0.25 \text{ ohm.} \\ \text{Resistance of entire circuit} &= 0.25 + 4 \\ &= 4.25 \text{ ohms.} \end{aligned}$$

Current through entire circuit

$$= \frac{1.5}{4.25} = 0.353 \text{ ampere.}$$

But suppose we divided cells up into two parallel rows of four cells in series, as in Fig. 117.

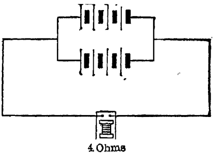

FIG. 117. The 8 cells are arranged in 2 parallel rows of 4 cells in series.

The e.m.f. of each series row would be

$$4 \times 1.5, \text{ or } 6 \text{ volts.}$$

Since the two rows are in parallel, the total e.m.f. would be the e.m.f. of one row, or 6 volts. The internal resistance of each row would be

$$2 \times 4, \text{ or } 8 \text{ ohms.}$$

But since the two rows are in parallel, the internal resistance of the whole combination of cells would be

$$\tfrac{8}{2}, \text{ or } 4 \text{ ohms.}$$

The resistance of the entire circuit would then be

$$4 + 4, \text{ or } 8 \text{ ohms.}$$

Current (through entire circuit)

$$= \frac{\text{voltage (across entire circuit)}}{\text{resistance (of entire circuit)}}$$

$$= \tfrac{6}{8} = 0.75 \text{ ampere.}$$

This is greater than the 0.6-ampere current when the cells were all in series, and the 0.353-ampere current, when they were all in parallel.

The general rule for the arrangement of cells to give the greatest current through any given resistance is:

Arrange the cells so that the internal resistance of the whole combination of cells is as nearly as possible equal to the external resistance to be overcome.

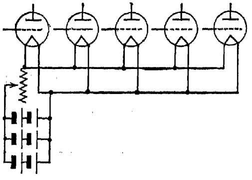

FIG. 118. Each of the 6 dry cells is required to deliver only ⅓ the current taken by the tubes.

Cells are not usually arranged to give the greatest current but to supply requisite current and have the longest life. Thus it requires 2 dry cells in series to light the filaments of 99-type vacuum tubes but in radio receiving sets where several of these tubes are required in multiple, 4 or 6 dry cells arranged as shown in Fig. 118 are more economical in the long run because the individual cells would be relieved of the heavier currents which would have to be delivered by a single pair.

To find the current which a certain combination of cells will force through a given resistance:

First:

Find the **total voltage** of the combination of cells.

Total voltage

$$= (\text{volts per cell}) \times (\text{number of cells in series}).$$

Second:

Find the **internal resistance** of the combination of cells.

Internal resistance

$$= \frac{(\text{resistance per cell}) \times (\text{number in series})}{\text{number of parallel rows}}.$$

Third:

Find the **total resistance** of the circuit.

Total resistance

$$= \text{external resistance} + \text{internal resistance}.$$

Fourth:

Find the **current** by Ohm's law.

$$\text{Total current} = \frac{\text{total voltage}}{\text{total resistance}}.$$

Example 7. In how many ways can 12 cells be arranged?

(1) 12 cells in series.
(2) 2 parallel sets of 6 cells in series.
(3) 3 parallel sets of 4 cells in series.
(4) 4 parallel sets of 3 cells in series.
(5) 6 parallel sets of 2 cells in series.
(6) 12 cells in parallel.

Example 8. Find the current which each arrangement of cells in the preceding example would send through an external resistance of 1.3 ohms. E.m.f. of each cell is 1.4 volts; internal resistance of each cell is 0.4 ohm.

(1) Twelve cells in series: Fig. 119.

First:

$$\begin{aligned}\text{Total voltage} &= (\text{volts per cell}) \times (\text{number of cells in series})\\ &= 1.4 \times 12\\ &= 16.8 \text{ volts.}\end{aligned}$$

Second:

$$\begin{aligned}\text{Internal resistance} &= \frac{(\text{res. per cell}) \times (\text{number in series})}{\text{number of parallel rows}}\\ &= \frac{0.4 \times 12}{1}\\ &= 4.8 \text{ ohms.}\end{aligned}$$

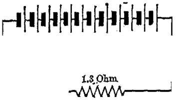

FIG. 119. Twelve cells in series.

Third:

$$\begin{aligned}\text{Total resistance} &= \text{internal resistance} + \text{external resistance}\\ &= 4.8 + 1.3\\ &= 6.1 \text{ ohms.}\end{aligned}$$

Fourth:

$$\begin{aligned}(\text{Total})\text{ current} &= \frac{(\text{total})\text{ voltage}}{(\text{total})\text{ resistance}}\\ &= \frac{16.8}{6.1}\\ &= 2.75 \text{ amperes.}\end{aligned}$$

(2) Two parallel sets of 6 cells in series: Fig. 120.

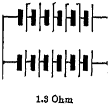

FIG. 120. Two parallel rows of 6 cells in series.

First:

$$\begin{aligned}\text{Total voltage} &= (\text{volts per cell}) \times (\text{number of cells in series})\\ &= 1.4 \times 6\\ &= 8.4 \text{ volts.}\end{aligned}$$

Second:

$$\begin{aligned}\text{Internal resistance} &= \frac{(\text{res. per cell}) \times (\text{number in series})}{\text{number of parallel rows}}\\ &= \frac{0.4 \times 6}{2}\\ &= 1.2 \text{ ohms.}\end{aligned}$$

Third:

$$\begin{aligned}\text{Total resistance} &= \text{internal resistance} + \text{external resistance}\\ &= 1.2 + 1.3\\ &= 2.5 \text{ ohms.}\end{aligned}$$

Fourth:

$$\begin{aligned}\text{(Total) current} &= \frac{\text{(total) voltage}}{\text{(total) resistance}}\\ &= \frac{8.4}{2.5}\\ &= 3.36 \text{ amperes.}\end{aligned}$$

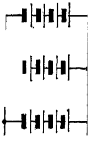

FIG. 121. Three parallel rows of 4 cells in series.

(3) Three parallel sets of 4 cells in series: Fig. 121.

First:

$$\begin{aligned}\text{Total voltage} &= \text{(volts per cell)} \times \text{(number of cells in series)}\\ &= 1.4 \times 4\\ &= 5.6 \text{ volts.}\end{aligned}$$

Second:

$$\begin{aligned}\text{Internal resistance} &= \frac{\text{(res. per cell)} \times \text{(number in series)}}{\text{number of parallel rows}}\\ &= \frac{0.4 \times 4}{3}\\ &= 0.53 \text{ ohm.}\end{aligned}$$

Third:

$$\begin{aligned}\text{Total resistance} &= \text{internal resistance} + \text{external resistance}\\ &= 0.53 + 1.3\\ &= 1.83 \text{ ohms.}\end{aligned}$$

Fourth:

$$\begin{aligned}\text{(Total) current} &= \frac{\text{(total) voltage}}{\text{(total) resistance}}\\ &= \frac{5.6}{1.83}\\ &= 3.06 \text{ amperes.}\end{aligned}$$

(4) Four parallel rows of 3 cells in series: Fig. 122.

First:

$$\begin{aligned}\text{Total voltage} &= (\text{volts per cell}) \times (\text{number of cells in series})\\ &= 1.4 \times 3\\ &= 4.2 \text{ volts.}\end{aligned}$$

Second:

$$\begin{aligned}\text{Internal resistance} &= \frac{(\text{res. per cell}) \times (\text{number in series})}{\text{number of parallel rows}}\\ &= \frac{0.4 \times 3}{4}\\ &= 0.3 \text{ ohm.}\end{aligned}$$

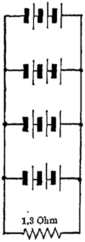

Fig. 122. Four parallel rows of 3 cells in series.

Third:

$$\begin{aligned}\text{Total resistance} &= \text{external resistance} + \text{internal resistance}\\ &= 1.3 + 0.3\\ &= 1.6 \text{ ohms.}\end{aligned}$$

Fourth:

$$\begin{aligned}(\text{Total}) \text{ current} &= \frac{(\text{total}) \text{ voltage}}{(\text{total}) \text{ resistance}}\\ &= \frac{4.2}{1.6}\\ &= 2.63 \text{ amperes.}\end{aligned}$$

(5) Six parallel rows of 2 cells in series: Fig. 3.

First:

Total voltage $= 2 \times 1.4 = 2.8$ volts.

Second:

$$\text{Internal resistance} = \frac{2 \times 0.4}{6} = 0.13 \text{ ohm.}$$

Third:

Total resistance $= 0.13 + 1.3 = 1.43$ ohms.

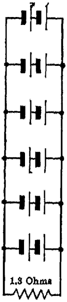

Fig. 123. Six parallel rows of 2 cells in series.

Fourth:

Total current $= \frac{2.8}{1.43} = 1.96$ amperes.

(6) Twelve cells in parallel: Fig. 124.

First:

Total voltage = 1.4 volts.

Second:

Internal resistance $= \frac{0.4 \times 1}{12} = 0.033$ ohm.

Third:

Total resistance = 0.033 + 1.3 = 1.333 ohms.

Fourth:

Total current $= \frac{1.4}{\quad} = 1.05$ amperes.

Note that the combination No. 2 (two parallel sets of 6 cells in series) gave the highest current, because in this case the internal resistance of the combination (1.2 ohms) was the most nearly equal to the external resistance (1.3 ohms).

FIG. 124. Twelve cells in parallel.

Prob. 21–6. What is the greatest current that 20 cells, each of 1.5 volts e.m.f. and 0.5 ohm internal resistance, can send through a 12-ohm resistance? How would the cells be arranged?

Prob. 22–6. What is the greatest current that the cells of Prob. 21–6 can send through a resistance of 5 ohms? How would the cells be arranged?

Prob. 23–6. What is the greatest current that the cells in Prob. 21–6 can send through a 0.4-ohm resistance? How would the cells be arranged?

Prob. 24–6. What is the greatest current that the cells of Prob. 21–6 can send through a 40-ohm resistance and how would the cells be arranged?

59. Zinc as Fuel. The action of the fluid in a cell consumes the zinc by uniting with it and forming a chemical compound of little commercial value. Thus the zinc may be considered a fuel, just as is the coal which is consumed under a boiler by the action of the oxygen in the air, and formed into ash. Since the cost of the energy obtained from using zinc in a battery is much greater than the cost of the energy obtained from coal burned under a boiler, the use of batteries is limited to places where a very small amount of power is required, as noted above.

60. Local Action. In a well-built cell, the chemical action which consumes the zinc goes on very slowly when the cell is not in use, so that a dry cell will last about a year if unused. The fact that there is any chemical action at all when the cell is not delivering current, is largely due to slight impurities, generally carbon, which are always present in zinc. The zinc, the carbon, and the fluid will form a little cell inside the larger cell, and set up an electric current. But since the speck of carbon is in direct contact with the zinc, the current will merely circulate around in the zinc plate. Thus zinc is consumed but no current is delivered to the outside circuit. If the zinc is amalgamated, that is, covered with mercury, thus covering up the impurities, local action will be greatly reduced.

61. Polarization. If we allow the dry cell or the wet cell previously described to deliver a current for a few minutes through some electrical appliance, we note that the current does not remain at its first value but falls off very rapidly. The terminal voltage likewise falls off in the same manner. But if the cell is left on open circuit for a half hour or so, and again put on to the same electrical appliance, we find that it acts exactly as before. The starting current and voltage are almost, if not quite, as much as before and again they both decrease very rapidly, if the cell is left connected.

The reason for this behavior is that there is a gas formed at the carbon plate by the chemical action going on in the cell. This gas, called **hydrogen**, soon covers the plate to such an extent that not much of the fluid is in contact with the plate. Of course this gives less area through which the current may flow from the fluid to the plate, and so increases the internal resistance of the cell. This collecting of hydrogen gas on the positive plate is called **polarization.**

If, however, the cell is now left disconnected a while, the hydrogen slowly disappears, being absorbed by chemicals placed near the carbon plate for this purpose.

The dry cells and wet cells thus described are called open-circuit batteries and should therefore be used on intermittent service only, such as bell ringing, spark coils, etc., to allow the positive plates to keep clear of hydrogen gas.

Special wet cells are built, in which the chemicals act more quickly in absorbing the hydrogen. These are called **closed circuit** cells and, of course, are the kind to be used for a continuous current.

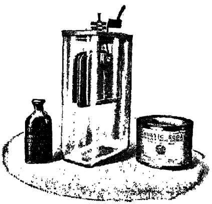

Fig. 125. A caustic-soda cell with can of renewal salts and oil to prevent evaporation. *Thomas A. Edison, Incorporated.*

62. Caustic Soda Cells — Rating. Although dry cells are the most used of the primary batteries, they cannot furnish large currents for long periods and it will be worth while to mention a wet cell having a zinc (−) plate, a copper oxide (+) plate and an electrolyte of caustic soda. These cells have come to be used almost universally in railway signal applications where primary batteries are required. For this purpose they are made

in two sizes, 500 and 1000 ampere-hours. Due to improved methods of manufacture these batteries have become very uniform, reliable and demand practically no attention between renewals. The internal resistance is low and there is practically no polarization, thus allowing the flow of currents for long periods if required.

The rating of these cells at 1000 ampere-hours, means that they can supply 1 ampere for 1000 hours or 0.5 ampere for 2000 hours. Thus the ampere-hour rating of a battery is the product of the current in amperes and the number of hours it can deliver this current before becoming completely discharged. The capacity of a standard $2\frac{1}{2}$-inch by 6-inch dry cell is about 25 ampere-hours.

63. Testing Dry Cells. Some dry cells are made for long intermittent service with small current requirements and have a large internal resistance. Others, the more common type, are made capable of supplying larger currents and have relatively small internal resistance. Because of this difference, a cell must be properly classified before testing.

A radio "B" battery (see Chapter VII) is required to furnish very little current but high voltage and is therefore built up in units of 15 small cells each or in groups of these units. The shop test on such batteries amounts simply to a voltmeter reading although this indicates absolutely nothing about the quality or probable life. This test would however indicate whether any individual cells were dead.

The standard telephone type of dry cell is tested with both voltmeter and ammeter. It should show an e.m.f. of 1.5 volts on open circuit and when new should show a momentary short-circuit current through the ammeter of 4 or 5 amperes.

The more common type of dry cell used for lighting small lamps, "A" battery radio service, etc., should show 1.5 volts on the voltmeter on open circuit and about 30 amperes on the ammeter. The voltage test is rarely used here as it

tells practically nothing provided the ammeter test is satisfactory.

Caution. In giving the ammeter test to these cells, it is important not to keep the circuit closed through the ammeter longer than necessary to get an indication as the large current will damage the cell.

64. Electrolysis. Electroplating. We have seen that whenever a current flows through the cells described above, some of the zinc plate is consumed by forming a chemical compound with the fluid. If, now, we apply a voltage to the cell from the outside and cause the current to flow in the opposite direction, the zinc will come out of the chemical composition and be deposited again on the zinc plate. This process is called **electrolysis.**

The amount of metal which one ampere will deposit from the solution in one hour is exactly the same amount which is taken from the plate by that solution, when a cell delivers a current of one ampere for one hour. It is called the **Electrochemical Equivalent** of the metal and varies with the different metals.

For	zinc the electrochemical equivalent is			0.0429 oz.
"	copper	"	"	0.0418 "
"	nickel	"	"	0.0386 "
"	silver	"	"	0.1421 "

Example 9. A battery runs for 80 hours at an average rate of 2 amperes. How many ounces of zinc are consumed?

1 ampere for 1 hour consumes 0.0429 oz.
2 amperes for 1 hour consume $2 \times 0.0429 = 0.0858$ oz.
2 amperes for 80 hours consume $80 \times 0.0858 = 6.86$ oz.

Prob. 25-6. How much zinc is consumed when a battery delivers 0.48 ampere for 145 hours?

Prob. 26-6. The zinc plate of a battery weighs 8 ounces. How long will it last if the battery delivers an average current of 0.7 amperes for 5 hours every day?

Prob. 27-6. The zinc plate of a battery weighed 20.1 ounces before any current was taken from the cell. After a run of 200

hours the plate weighed 13.7 ounces. What average current was taken from the cell, allowing for no local action?

The greatest use which is made of this fact, that the current will deposit metal from solutions, is in **Electroplating.** Thus, in Fig. 126, a piece of copper and a piece of iron are immersed in a solution of copper sulphate. If a current is now sent from the generator *G* through the liquid from the copper to the iron, the copper will be separated from the solution of copper sulphate and deposited on the iron. The iron will then be copper plated. As fast as the copper goes out from the solution and is deposited upon the iron, more copper comes off the piece of copper and goes into the solution to replace that which goes to the iron from the solution.

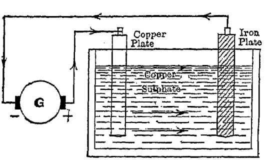

FIG. 126. The iron becomes copper plated when a current is sent through the cell as indicated.

If we desired to silver plate the iron, we would use a silver solution and a piece of silver in place of the copper plate. A nickel solution and a nickel strip would produce a nickel plate on the iron, etc.

If by any chance the current were reversed, the plate would become plated with whatever metal was in the solution.

65. Electrotyping. The object of electrotyping is to reproduce the printers' set-up type, engravings, etc. A wax impression is first taken of the set-up type. Since wax is a non-conductor of electricity, the wax mold is now given a thin coating of graphite. The whole mold with its coating of graphite is immersed in copper sulphate together with a copper bar. An electric current is now sent through from the copper to the graphite. This causes copper to be deposited on the graphite just as it was de-

posited on the iron in the cell of the previous paragraph. The current is allowed to run long enough to deposit a plate of sufficient thickness to be handled safely. Then the wax mold is removed and the copper plate remaining is an exact reproduction of the type.

66. Refining of Metals. Since the metal, which is deposited on the negative plate, is remarkably pure, this method is often used to separate a metal from impurities. The impure mass is made the positive plate. When an electric current is passed through the cell, the pure metal is gradually dissolved by the electrolyte and carried over to the negative plate. At the end of the process the negative plate is found to consist of very pure metal, since practically all the impurities remain at the positive plate.

For exact data and methods of procedure in the above processes, see "Metallurgical and Chemical Engineering" and "Transactions of American Electrochemical Society."

Prob. 28-6. How long will it take to refine 175 pounds of copper if a current of 100 amperes can be used?

Prob. 29-6. An iron casting is to be copper plated and then nickel plated. The current in each case is to be 10 amperes. How long must it remain in each vat in order to have 14 ounces of each metal deposited on it?

Prob. 30-6. Two electroplating vats are arranged in series, one for nickel plating and the other for silver plating. If a current flowing through the vats deposits 2 ounces of silver in a given time, how much nickel is deposited at the same time?

67. Electrolytic Destruction of Metal Water Mains, etc. It is customary in electric railways to use the track as the return circuit. The rails, not being insulated from the ground, allow the current to leak into the ground and to follow any low-resistance path it can find, such as a water or a gas main, back to generator, which of course, is also grounded.

Fig. 127 is a diagram of this action. Where the current enters the pipe at A no harm is done. But at the point B where the current leaves the pipe, generally near the generator station, there is all the action that takes place at the positive plate in an electroplating vat. The pipe, being in moist ground, is in contact with water containing more or less salt, which causes it to act as an electrolyte. Thus, as the electric current leaves the pipe, there is a chemical action set up between the pipe and salt water, by which the iron of the pipe is eaten away in places, and carried by the electric current to some outside substance, which for the instant is acting as the negative plate.

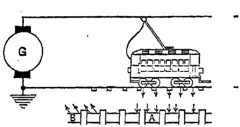

FIG. 127. An electric current is gradually eating away the pipe at B.

Heavy iron pipes have been eaten through in a short time by this action. Among the various precautions taken to avoid this destruction by electrolysis are the following: (1) The heavy bonding of the rails to procure a return of low resistance. (2) The use of a second trolley wire for the return. (3) Tapping a return line on to the water mains, to conduct back to the generator whatever current they may be carrying, without allowing it to flow through the ground and produce electrolytic action.

Method No. 2 is the most efficient, but also the most expensive and is very seldom used.

68. Storage Batteries. In the ordinary primary cells, when the negative plate is nearly consumed, it is customary to replace it by another. If, instead of replacing the worn-out negative plate, we send a current from an outside source through the cell in the reverse direction, and deposit the metal back on the negative plate, the cell is then called a **storage battery.** When such a cell is delivering current it

is said to be **discharging**; when receiving current, it is said to be **charging**. A storage cell differs in no fundamental respect from a primary cell. Any primary cell could be used as a storage cell and have its negative plate restored by electrolysis as an ordinary storage battery does. It is not commercially economical, however, to do this in the case of any but a few cells, especially constructed for this purpose.

Remember that a storage cell **does not store electricity**. It stores nothing but chemical energy. In charging, electrical energy is transformed into chemical energy and stored in the cell; in discharging, this chemical energy is changed back again into electrical energy.

Of course there are losses in both transformations which prevent an efficiency of 100 per cent. For one thing, the terminal voltage **applied to** the cell on charge must be higher than that **supplied by** the cell on discharge at the same current rate, partly because, in each case, the internal resistance of the cell must be overcome.

In charging a cell, the current must be sent in **against** the e.m.f. and the resistance of the cell, while on discharge, part of the e.m.f. of the cell must be used to overcome this internal resistance in forcing a current to flow through it in the other direction; so that only **part of the e.m.f.** is available as terminal voltage. In this respect it is merely like any other electrical machine. Therefore an electric storage battery never gives out as much energy as is put into it; the best types generally give out about 75 per cent of the input.

69. Lead Cells. Two materials, lead and lead peroxide, have been found to work well in a cell which can be used as a storage battery; lead for the negative plate and lead peroxide for the positive plate. The liquid used is a half-and-half mixture of sulphuric acid and water. The e.m.f. obtained is about 2.00 volts. The internal resistance is very low, about 0.0015 ohm, which allows the cell to deliver a very

large current for its size. By putting enough cells in series, any desired voltage may be obtained.

Example 10. A lead cell has an e.m.f. of 2.00 volts and an internal resistance of 0.004 ohm. What will the terminal voltage be when discharging 20 amperes?

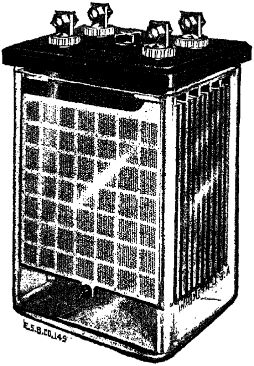

FIG. 128 (a). Lead storage battery; stationary type. *The Electric Storage Battery Co.*

Volts to send 20 amperes through 0.004 ohm $= 0.004 \times 20$ $= 0.08$ volts.

Terminal volts on discharge = e.m.f. − volts to overcome internal resistance
$= 2.00 - 0.08$
$= 1.92$ volts.

Example 11. What voltage would have to be impressed across the storage cell of the above example in order to charge it at 20 amperes?

Volts to overcome internal resistance $= 0.004 \times 20 = 0.08$ volt.

$$\begin{aligned}\text{Volts to charge} &= \text{e.m.f.} + \text{volts to overcome internal resistance}\\ &= 2.00 + 0.08\\ &= 2.08 \text{ volts.}\end{aligned}$$

Prob. 31–6. A lead storage cell has an e.m.f. of 2.04 volts and an internal resistance of 0.0025 ohm. The normal charging current is 35 amperes. What is its terminal voltage on charge?

Prob. 32–6. What is the terminal voltage of the cell in Prob. 31–6, when discharging at twice its normal rate?

Prob. 33–6. How many lead cells, each having an e.m.f. of 2 volts and an internal resistance of 0.005 ohm, will it take to light 10 incandescent lamps which are arranged in parallel? Each lamp requires 0.5 ampere at 32 volts.

Prob. 34–6. A battery of 15 lead cells is to be charged in series from a 110-volt line. Each cell has an e.m.f. of 2.02 volts and an internal resistance of 0.006 ohm. How many ohms resistance must be placed in series with the cells so that the current shall not exceed 25 amperes?

Prob. 35–6. A set of 80 lead storage cells, each having 2.02 e.m.f. and 0.005 ohm internal resistance, is to be charged in two parallel sets of 40 cells in series. Each cell has a normal charging current of 40 amperes. What must be the terminal voltage of the generator?

Prob. 36–6. If the cells in Prob. 35–6 are discharged in series at the normal rate, what will be the terminal voltage of the set?

Prob. 37–6. A set of 96 lead storage cells, each having 2 volts e.m.f. and 0.004 ohm internal resistance, is to be charged from a 110-volt line. If each cell is to take its normal current of 20 amperes, what would be the best arrangement of cells in order to have least power lost in a series resistance in the line?

Prob. 38–6. How could the cells in Prob. 37–6 be arranged in order to deliver 160 amperes and not exceed the normal current of each cell? At what terminal voltage would they deliver this current?

70. Rating of Storage Batteries. A storage battery is rated as to the number of **ampere-hours** it can deliver and the time in which it delivers this number of ampere-hours. Thus a cell may have an 80-ampere-hour capacity at an

8-hour rate. That is, it would maintain a current of 10 amperes for 8 hours.

Lead cells are usually rated on a steady discharge for 8 hours because they work best when discharged at such a rate that they need recharging only at the end of an 8-hour run. For instance, an ordinary lead cell may average a capacity of,

100 amp-hr.	at	8-hr.	rate	(that is,	at $12\frac{1}{2}$	amperes),
84	"	" 4-hr.	"	"	" 21	"
64	"	" 2-hr.	"	"	" 32	"
50	"	" 1-hr.	"	"	" 50	"

This means that this cell will deliver a current of

50	amperes	for 1	hr.	$(50 \times 1) = 50$	ampere-hours.
32	"	" 2	"	$(32 \times 2) = 64$	"
21	"	" 4	"	$(21 \times 4) = 84$	"
$12\frac{1}{2}$	"	" 8	"	$(12\frac{1}{2} \times 8) = 100$	"

This shows conclusively that of the above rates of discharge, the 8-hour rate, or $12\frac{1}{2}$ amperes, gives by far the greatest capacity to the cell.

In making up a combination of storage cells to deliver a certain current at a certain voltage, enough cells are arranged in series to produce the required voltage. Then enough parallel rows of these series sets are used so that each cell may deliver approximately its normal 8-hour current. The plate composed of the smaller number of "grids" is always the positive plate.

71. Care of Lead Storage Cells.

(1) Charge and discharge the cells, whenever possible, at about the 8-hour rate. Never discharge station-type batteries faster than twice the 1-hour rate, and never for more than 30 seconds at this rate.

(2) In charging, connect the positive terminal of the power supply to the positive terminal of the cell and regulate the

current by a rheostat. Of course only direct current will charge a cell.

(3) Be sure that no impurity, such as any metal or acid, gets into the cell.

(4) Keep the fluid about 1.2 times as heavy as water. A hydrometer when floating in the cell should read about 1200 to 1250.

This may differ somewhat depending on the original concentration. See manufacturer's instructions.

(5) Never discharge a cell so far that the hydrometer sinks below the "discharged" indication as prescribed by the manufacturer. Usually this is between 1150 and 1175.

(6) Never allow a cell to stand discharged. Recharge immediately.

(7) If the plates grow white, give the cell long-continued overcharges.

(8) When a cell is to remain unused for a long time, give it an hour or two of freshening charge about once or twice a month.

(9) Never allow an open flame or an electric spark near the opening of a storage battery on charge, as the mixture of oxygen and hydrogen gas in the top of the cells is highly explosive.

(10) Remember that the electrolyte, sulphuric acid, will eat holes in clothing and char wood or other vegetable matter if allowed to touch them. The destroying action can be neutralized by the immediate application of a strong solution of ammonia.

72. The Edison Storage Cell. The Edison storage cell when fully charged consists of a positive plate of nickel oxide and a negative plate of spongy iron, in a solution of caustic potash. The whole is contained in a steel container, which makes this cell much less liable to damage than the usual lead cell.

The voltage of the Edison cell at its normal discharge

rate is only 1.2 volts as against 2.00 volts of the lead cell.

The Edison storage cell can be left charged or discharged for an indefinite time without being harmed. As seen by

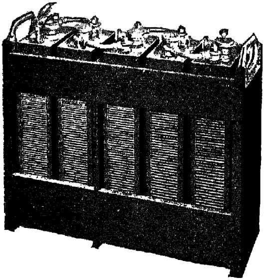

FIG. 128 (*b*). Battery of 5 Edison storage cells in tray. *Edison Storage Battery Co.*

the previous paragraph, such treatment would ruin a lead cell.

The temperature of the electrolyte Edison cell should be kept at about 70° F. An Edison cell is not injured by high temperatures, which cause lead cells to deteriorate rapidly. On the other hand, Edison cells lose nearly all their capacity at very low temperatures, which cause no trouble to lead cells. It must be said, however, that Edison cells operate successfully in cold climates, because the very act of taking current from them warms them up to an efficient temperature.

SUMMARY OF CHAPTER VI

AN ELECTRIC BATTERY transforms chemical energy into electrical energy. It consists of two unlike conductors called positive and negative plates immersed in a fluid which attacks one of the plates chemically. The voltage set up by this chemical action is called the electromotive force, commonly written e.m.f.

DRY CELLS consist of a positive plate of carbon surrounded by plaster paste containing sal ammoniac solution. These are placed in a zinc cup which forms the negative plate. Can be used for intermittent service only; e.m.f., about 1.5 volts; internal resistance, less than 0.1 ohm. Cheap and convenient.

A reliable WET CELL capable of supplying large currents over long periods of time has a negative plate of zinc, a positive plate of copper oxide and an electrolyte of caustic soda. E.m.f. about 0.9 volt.

The CURRENT which a cell is delivering depends upon the external and internal resistance of the circuit.

$$\text{Current} = \frac{\text{e.m.f.}}{(\text{external resistance}) + (\text{internal resistance})}.$$

The TERMINAL VOLTAGE of a cell when not delivering current equals its e.m.f. When a cell is delivering current the terminal voltage is the voltage across the external circuit only. Thus, it is that part of the e.m.f. which is not used to send the current through the inside of the cell. The greater the current, the lower the terminal voltage.

Terminal volts = e.m.f. − volts (across internal resistance).

Volts (across internal resistance) = internal resistance × current (through cell).

The SERIES ARRANGEMENT is best when the external resistance is high. With this arrangement,

$$(\text{Total})\ \text{current} = \frac{(\text{total})\ \text{e.m.f.}}{(\text{total})\ \text{resistance}}.$$

$$\begin{aligned}
\text{Total e.m.f.} &= \text{e.m.f. per cell} \times \text{number of cells.}\\
\text{Total resistance} &= \text{external resistance} + \text{internal resistance.}\\
\text{Internal resistance} &= (\text{resistance per cell}) \times (\text{number of cells}).
\end{aligned}$$

The PARALLEL ARRANGEMENT of cells is best when the external resistance is very low. With this arrangement,

$$\text{Total current} = \frac{\text{total e.m.f.}}{\text{total resistance}}.$$

$$\text{Total e.m.f.} = \text{e.m.f. of one cell.}$$

$$\text{Total resistance} = \text{internal resistance} + \text{external resistance.}$$

$$\text{Internal resistance} = \frac{\text{resistance per cell}}{\text{number of cells}}.$$

The ARRANGEMENT FOR GREATEST CURRENT is such a combination of series and parallel, that the internal resistance of the combination of cells equals the external resistance of the circuit.

The current is found by the usual equation,

$$\text{(Total) current} = \frac{\text{(total) e.m.f.}}{\text{(total) resistance}}.$$

$$\text{Total e.m.f.} = \text{e.m.f. per cell} \times \text{number of cells in series.}$$

$$\text{Total resistance} = \text{internal resistance} + \text{external resistance.}$$

$$\text{Internal resistance} = \frac{\text{resistance per cell} \times \text{number in series}}{\text{number of parallel sets}}.$$

The ZINC IS CONSUMED AS A FUEL in batteries. Its high cost prevents extensive use of batteries as a source of electric power.

LOCAL ACTION is set up when there are any impurities on the surface of the zinc. This impurity (together with the fluid and zinc) sets up a small local current which consumes the zinc, but produces no terminal voltage.

POLARIZATION is the forming of bubbles of hydrogen gas on the positive plate, which increases the resistance. They are removed by chemicals which are put into the solution for that purpose. But these chemicals act so slowly that if the wet and dry cells in general use are not allowed to rest after every very short run, they become so badly polarized that the terminal voltage is almost zero.

TEST small dry cells, designed to supply definite voltages but small currents, with the voltmeter only. All standard dry cells should be tested with the ammeter, the long-life, low-

current type testing about 4 or 5 amperes and the more common type about 30 amperes.

ELECTROLYSIS is the opposite of the battery effect. When a current is sent through a metal salt solution, it takes the metal out of solution and deposits it on the negative plate. The weight of metal deposited is always the same per ampere-hour for the same solution. By sending a current through copper sulphate, the copper is deposited on the negative plate, which may consist of wax prints of set-up type, etc. Silver plating is done in the same way by using a solution of silver nitrate.

ELECTROLYTIC DAMAGE TO WATER MAINS takes place whenever the current of electricity, which has been flowing along it, leaves the pipe to go to some other conductor.

STORAGE BATTERIES make use of electrolysis by the possibility of sending a current in the reverse direction through a cell. This redeposits on the negative plate the metal which has been consumed by the fluid. Common types have spongy lead for the negative plate, lead peroxide for the positive plate, and dilute sulphuric acid as the fluid. Their e.m.f. is about 2.00 volts; internal resistance, very low.

STORAGE BATTERIES ARE RATED as to the number of ampere-hours they will give out, in a given time. They are usually rated on the current they can maintain for 8 hours. The capacity grows rapidly less as the time is decreased, being about $\frac{1}{2}$ as great if allowed to discharge in 1 hour.

EDISON STORAGE BATTERY consists of a negative plate of spongy iron, a positive plate of nickel oxide; fluid, caustic potash. E.m.f. about 1.2 volts; internal resistance, a little larger than that of lead cells. Light and rugged. Efficient temperature range is limited. Can remain charged or discharged indefinitely without harm.

FOR CARE OF LEAD STORAGE CELLS. See page 148.

PROBLEMS ON CHAPTER VI

Prob. 39–6. What current flows when 5 cells are connected in series to a circuit having 12 ohms resistance? Each cell has an e.m.f. of 1.48 volts and an internal resistance of 0.4 ohm.

Prob. 40–6. A telegraph line consists of 5000 feet of No. 8, B. & S. gage E. B. B. iron wire. There are two relays on the line, each having 150 ohms resistance. How many cells will be required to send 0.25 ampere through the above line, and how would you arrange them? Each cell has 1.3 volts e.m.f. and 4 ohms internal resistance.

Prob. 41–6. Suppose that 56 storage cells, each having an e.m.f. of 2.1 volts and an internal resistance of 0.015 ohm, are to be used to light 15 incandescent lamps of 200 ohms each, arranged in parallel.

(*a*) What current flows through the main line?

(*b*) What current flows through each lamp?

(Neglect resistance of line wires.)

Prob. 42–6. If the line wires of Prob. 41–6 have a total resistance of 0.6 ohm, what current will the cells deliver?

Prob. 43–6. What is the terminal voltage of the cells:

(*a*) In Prob. 41–6?

(*b*) In Prob. 42–6?

Prob. 44–6. What would be the voltage at the terminals of the lamps in Prob. 42–6?

Prob. 45–6. What power is lost in the line in Prob. 42–6?

Prob. 46–6. What power is lost in the cells in Prob. 42–6?

Prob. 47–6. The terminal voltage of a certain cell is 1.2 volts when delivering 2.2 amperes. When delivering 3 amperes the terminal voltage is 0.9 volt. What is the internal resistance of the cell?

Prob. 48–6. How many cells, each having an e.m.f. of 1.08 volts and an internal resistance of 2 ohms, would be required to operate a telegraph line having a total resistance of 100 ohms? A current of 0.25 ampere is used in this telegraph line.

Prob. 49–6. A battery of 6 dry cells in series is used to send a current through a resistance of 0.08 ohm. Each cell has an e.m.f. of 1.5 volts and an internal resistance of 0.05 ohm. How much current flows?

Prob. 50–6. If the cells in Prob. 49–6 were arranged in parallel, how much current would flow through the external circuit?

Prob. 51–6. If the cells in Prob. 49–6 were arranged in 2 parallel sets of 3 cells in series, how much current would flow through the external circuit?

Prob. 52–6. How much current would flow through each cell:
(*a*) In Prob. 49–6?
(*b*) In Prob. 50–6?
(*c*) In Prob. 51–6?

Prob. 53–6. What current would flow through the external circuit if the cells in Prob. 49–6 were arranged in 3 parallel sets of 2 cells in series?

Prob. 54–6. The normal current of each storage cell in a certain battery is 5 amperes, its internal resistance is 0.002 ohm, and e.m.f. is 2.05 volts. The cells are required to light 40 incandescent lamps each taking $\frac{1}{2}$ ampere at 112 volts. Consider the line wires of negligible resistance. How many cells are necessary and how should they be arranged?

Prob. 55–6. If a line wire of 0.3 ohm were used in Prob. 54–6, how many cells would be required and how should they be arranged?

Prob. 56–6. What would be the terminal voltage of the set of cells used in Prob. 55–6?

Prob. 57–6. A generator delivers 120 amperes at 115 volts. A battery of storage cells, whose normal discharge rate is 40 amperes, is kept as reserve, in case of accident to the generator. If the battery were to be large enough to take the place of the generator for 1 hour, how many cells must be used, and how should they be arranged? Each cell has an e.m.f. of 2.10 volts and an internal resistance of 0.0015 ohm.

Prob. 58–6. If the cells of Prob. 57–6 were charged as connected in Prob. 57–6, what charging voltage would be necessary?

Prob. 59–6. What charging voltage would be necessary to charge the battery as connected in Prob. 54–6?

Prob. 60–6. A Christmas tree is to be lighted by 20 miniature incandescent lamps each taking 0.8 ampere at 6 volts. How many storage cells would you use to light the tree for one hour? Each cell has an e.m.f. of 2.10 volts, an internal resistance of 0.008 ohm, and a normal current rate of $\frac{5}{8}$ ampere. Assume the short copper line wire to have a resistance of 0.02 ohm. State how you would arrange the lamps and the cells.

Prob. 61–6. If the lamps of Prob. 60–6 were to be lighted from a 110-volt circuit:

(*a*) How would you arrange the lamps?

(*b*) What resistance would it be necessary to place in series with the lamps?

Prob. 62–6. A cheap voltmeter with a resistance of 50 ohms was used to test the voltage across the terminals of a $4\frac{1}{2}$-volt "C" radio battery. Although the e.m.f. of the battery was actually $4\frac{1}{2}$ volts, the voltmeter read only 4.2 volts.

(*a*) What current flowed through the voltmeter?

(*b*) What was the internal resistance of the battery?

Prob. 63–6. If a voltmeter having a resistance of 100 ohms had been used to test the battery of Prob. 62–6, what would it have read?

Prob. 64–6. A reasonably good voltmeter for battery testing has about 100 ohms resistance per volt of scale. If a 6-volt voltmeter of this quality is used to test the battery of Prob. 62–6, what will it read? How much current will it take from the battery?

Prob. 65–6. A 500-ampere-hour "Edison Primary Battery" used in a telephone plant has an internal resistance of 0.02 ohm and when delivering 0.030 amperes has a terminal voltage of 0.65 volt. What is its e.m.f. under these conditions?

Prob. 66–6. What is the resistance of the external circuit under the conditions of Prob. 65–6?

Prob. 67–6. A new telephone dry cell has an e.m.f. of 1.5 volts and an internal resistance of 0.3 ohm.

(*a*) What would a battery-testing ammeter read if placed directly across its terminals?

(*b*) What current would flow if a 0.3-ohm resistor were placed across the terminals of this cell?

(*c*) What would the terminal voltage be under condition (*a*)? Under condition (*b*)?

Prob. 68–6. A man attempted to supply his automobile lamps from 4 of the cells of Prob. 67–6 in series in the place of his run-down storage battery. The lamps take 10 amperes when operating normally on a storage battery with a terminal voltage of 6 volts. What current did this man get through the lamps?

Prob. 69–6. (*a*) What was the terminal voltage of the 4-cell battery in Prob. 68–6?

(*b*) How many of these cells in series would be required to make the lamps burn at full brilliancy?

(*c*) If (*b*) is not possible, what is the least number of these cells which would give the 10 amperes under these conditions and how would they be arranged?

Prob. 70–6. Repeat Prob. 68–6 with cells having an internal resistance of 0.05 ohm but the same e.m.f.

Prob. 71–6. Repeat Prob. 69–6 with the cells of Prob. 70–6.

Prob. 72–6. A certain lead storage battery has 4 (+) rectangular plates 11 × $10\frac{1}{2}$ inches. What should the rating of this cell be if 55 ampere-hours per square foot of positive plate area are allowed?

Prob. 73–6. Suppose in Fig. 129, each of the resistors has a resistance of 5 ohms and the internal resistance of the battery is 10 ohms. What current flows in each resistor?

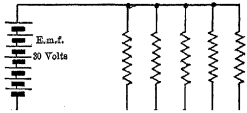

FIG. 129. Storage battery supplying current to several branches in parallel.

Prob. 74–6. If one of the resistors is removed in Prob. 73–6, what current flows in each of the remaining resistors?

Prob. 75–6. If 3 of the resistors are removed in Prob. 73–6, what current flows in each of the remaining pair?

Prob. 76–6. Repeat Prob. 73–6 if the battery has an internal resistance of 0.03 ohm.

CHAPTER VII

ELECTRICAL DEVICES AND CIRCUITS

73. Magnets. Almost all electrical signaling and communication devices depend upon magnets of one kind or another for their action. It is essential then, before taking up the study of these devices, to learn some of the facts about magnets.

If several turns of wire are wound around a hollow pasteboard tube, and the terminals of the coil thus formed are connected to a dry battery as shown in Fig. 130, an electric current will flow in the wires around the tube in the definite direction indicated by the arrowheads. As soon as the current begins to flow, we find that all around the coil, both inside and outside, there exists a magnetic effect which may be detected by means of a magnetic compass.

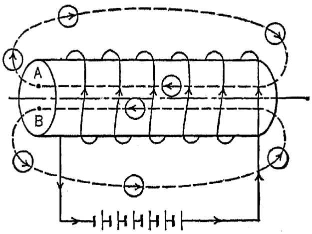

FIG. 130. Coil carrying current. Dotted lines indicate magnetic flux.

Suppose we place a small pocket compass at point A near the left end of the tube a little above the center line and then move the compass in the direction in which its north pole points, continuously changing the direction of motion as the needle swings around. We find that this procedure takes the compass around a path indicated by the dotted line returning it inside the tube to the starting point. If we had started at a point B just below the center line, the

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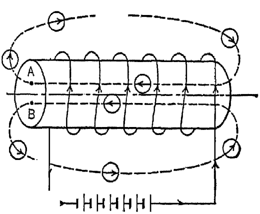

FIG. 130. Coil carrying current. Dotted lines indicate magnetic flux.

Suppose we place a small pocket compass at point A near the left end of the tube a little above the center line and then move the compass in the direction in which its north pole points, continuously changing the direction of motion as the needle swings around. We find that this procedure takes the compass around a path indicated by the dotted line returning it inside the tube to the starting point. If we had started at a point B just below the center line, the

path would have extended around the lower part of the tube rather than around the upper part. These lines along which the exploring magnet points are called lines of magnetic flux, and they have the direction indicated by the north pole of the magnetic needle. The direction of the flux lines depends upon the direction of the current in the coil and these relative directions may be remembered by the following

Thumb Rule: Grasp the coil with the right hand so that the fingers point in the direction of the electric current; then the thumb will indicate the direction of the magnetic flux lines inside the coil. Fig. 131 illustrates the application of the thumb rule to the case just considered.

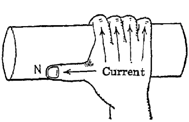

FIG. 131. Fingers point in direction of electric current; thumb points in direction of magnetic flux inside the coil.

The magnetomotive force, or the cause of the magnetic flux in a coil depends upon two things, the current in the wires and the number of turns in the coil, or we may say that it depends upon the number of ampere-turns, that is, upon the product of the amperes times the turns. From this is is at once seen that a certain magnetomotive force can be produced by a few turns carrying a large current or by many turns carrying a small current.

Example 1. What is the magnetomotive force of a coil formed by winding 200 turns of No. 22 wire on a pasteboard tube when the current in the coil is 0.5 ampere?

$$\begin{aligned}\text{Ampere-turns} &= \text{amperes} \times \text{turns} \\ &= 0.5 \times 200 = 100 \text{ ampere-turns.}\end{aligned}$$

Example 2. What magnetomotive force is produced when a coil of 1000 turns of No. 36 magnet wire, wound on a soft iron core, carries a current of 0.1 ampere?

$$0.1 \times 1000 = 100 \text{ ampere-turns.}$$

Thus, in the two examples, a magnetomotive force of 100 ampere-turns is produced, either by 200 turns carrying 0.5 ampere or by 1000 turns carrying 0.1 ampere. The magnetic effect would be the same in both cases if the di-

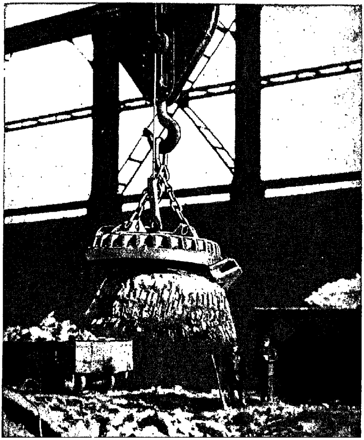

FIG. 132 (*a*). Large lifting magnet in action. *Cutler Hammer Inc.*

mensions of the coils were the same and if the wires were surrounded with the same substance.

But in the first example the core of the coil is air and in the second it is soft iron. This makes a great difference in the magnetic effects in the two cases. The second coil with the soft iron core produces many times the magnetic flux of the first one having the air core. That is, the magnetomotive

force finds it much easier to set up flux in iron than in air. We sometimes express this fact by saying that iron has a greater **permeability** than air. Substances with high permeabilities are called magnetic substances. The irons and steels, and some of the alloys of iron with tungsten, cobalt, and nickel are the chief magnetic substances. The material having the greatest permeability yet produced is an alloy of iron and nickel invented just a few years ago by Mr. G. W. Elmen of the Bell Telephone Laboratories in New York City.

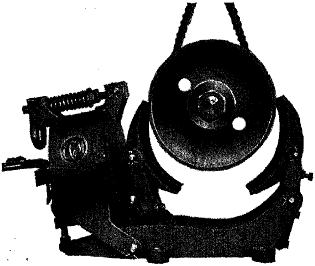

FIG. 132 (*b*): Magnetic Brake. *The Electric Controller and Mfg. Co.*

The device described in Example 2 is the simplest form of an **electromagnet.** Such electromagnets play important parts in the operation of electric bells, relays, automatic switches and a great variety of other signaling and industrial control equipment as well as in generators, motors and transformers. Fig. 132 (*a*) shows a large lifting magnet in action. Fig. 132 (*b*) shows a magnetic brake which, when in operation, grips the pulley.

If a bar of hard steel is placed inside a coil similar to that in Fig. 130 and a strong magnetomotive force is applied, the steel bar will be found to retain a large portion of the mag-

netism after removal from the coil. In other words the steel bar becomes a **permanent magnet.** Needles of magnetic compasses, ordinary bar or horseshoe magnets, and magnets in magnetos are examples of permanent magnets. The end

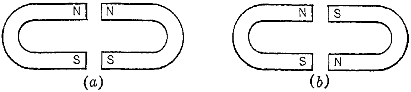

FIG. 133 (a). Two horseshoe magnets with like poles close together repel each other with increasing force as they are brought closer together. (b) Two horseshoe magnets with unlike poles near together attract each other with increasing force as they come closer together.

of an electromagnet or of a permanent magnet from which the flux lines leave is called the north pole and the one where they enter is called the south pole. Like poles repel each other and unlike poles exert forces of attraction on each other. (See Fig. 133.) Magnetic poles also attract unmagnetized magnetic materials by making them temporary magnets.

Prob. 1–7. Sketch some of the magnetic flux lines around a straight bar magnet. Indicate the poles by the letters N and S.

Prob. 2–7. An electric buzzer has two coils wound on soft iron cores as shown in Fig. 134. The piece of iron A is called the armature and is attracted by the electromagnets. Sketch some of the lines of magnetic flux due to the current in the coils.

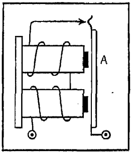

FIG. 134. Electric buzzer.

Prob. 3–7. Which would produce the greater magnetizing effect when wound on the same soft iron core, 100 turns carrying 5 amperes or 1500 turns carrying 0.2 ampere? What is the magnetomotive force in each case?

Prob. 4–7. If you were to design a doorbell requiring a definite magnetomotive force to operate, what differences in

size of wire and number of turns would you select for two different models, one to operate on one dry cell and the other to operate directly from a 30-volt farm lighting source; that is, which one would use the smaller wire and the fewer turns?

74. Electric Bells. The simplest single-stroke bell is constructed as in Fig. 135. When the button P is pushed, the battery sends a current through the coils of the electro-

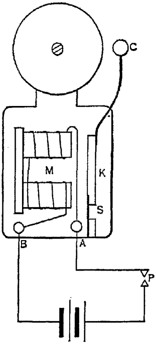

FIG. 135. Single-stroke electric bell.

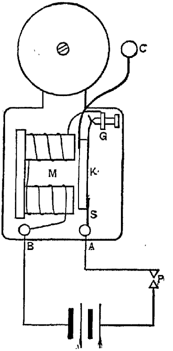

FIG. 136. Vibrating-stroke bell. Circuit-breaking type.

magnet M. The magnetic attraction then draws the armature K over toward the magnet, the clapper C hitting the bell. As long as the points at P are in contact, the armature K remains against the magnet. But on releasing the button, the contact points separate, and the circuit through the electromagnet is broken. This releases the armature K, which is pulled back into place by the spring S.

The same form of bell with vibrating stroke is shown in Fig. 136. When the button P is pushed, the circuit is

closed and a current flows through the coils on the electromagnet *M*. This causes the armature *K* to be drawn toward the magnet, the clapper *C* hitting the bell. But as the armature is drawn toward *M*, it moves away from the set screw *G*. This causes the circuit to be broken at that point, so the magnet *M* loses its magnetizing force and no longer attracts the armature *K*. The spring *S* then causes *K* to fly back and again make contact at *G*. The current once more flows through the magnet and again *K* is pulled over, and the bell struck. This vibrating action takes place very rapidly, as long as the button *P* is held down. Bells so constructed are very cheap and are in common use, battery cells being used as a source of power. But when the electric lighting circuit is used to ring the bells the points at *G* soon become fouled on account of the excessive sparking which takes place every time the circuit is opened at this point. To avoid this, two other types of vibrating-stroke bells are in common use: the **short-circuit bell**, Fig. 137, and the **differential bell**, Fig. 138.

Note in the case of the short-circuit or shunt bell that when the circuit is closed at *P*, the current goes through the windings on the magnet *M* and draws the armature *K* over. This makes a contact at *G*, which shunts the current around through the short circuit thus made, and almost no current is left flowing through the coils on *M*. This weakens the magnet so much that the armature *K* is brought back by the spring *S*: thus a vibrating stroke is produced.

Note that a lamp *L* is connected in series with the bell when it is used on a 110-volt line. If it were not for this lamp, the coils on the magnet would have the same current flowing through them, whether there was a contact at *G* or not, because the magnet coils would always be directly across the 110-volt line. The 110 volts would always force the same current through them, regardless of whether or not there was a short circuit around them.

When the circuit is closed at P the lamp allows just a certain amount of current to enter the bell. When all of this current is allowed to go through the coils on the magnet, the armature is drawn over. But when the greater part of this current is allowed to go through the short-circuit shunt, as explained above, the magnet becomes very weak.

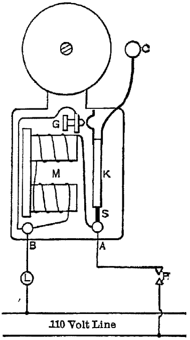

FIG. 137. Vibrating-stroke bell. Short-circuit type.

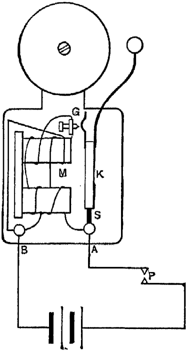

FIG. 138. Vibrating-stroke bell. Differential type.

This type of bell would soon run a battery down, hence it is rarely used except on a lighting circuit, with a lamp or some other resistance in series with it.

The differential bell of Fig. 138 will work either on a battery or on the lighting circuit with a lamp in series with the bell.

When P is pressed, the current goes through the winding near the pole tips of the magnet M. This draws over the armature, making contact at G, so that a current also goes

through the magnet winding shown near the yoke. But note that the currents in the two coils set up magnetic fields which oppose each other. The result, if the coils are properly arranged, is no magnetic force at all. The armature is then drawn back by the spring *S*, which breaks the current in the coils near the yoke. Then the current in the other coils again magnetizes *M* and draws the armature over, thus producing a vibrating stroke.

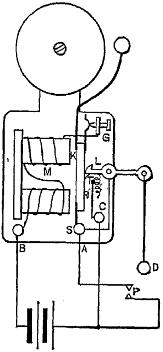

FIG. 139. Continuous-ringing bell.

In Fig. 139, the bell has an added terminal *C* which is connected directly to the battery. When the circuit is closed at *P* the armature is drawn toward the magnet. This releases the lever *L* from the detent *T*, and a small spring pulls it into contact with the post *R*, which is connected to *C*. Thus a circuit is at once completed from the battery to *A* through the terminal *C*, the post *R* and the lever *L*, which is connected directly to terminal *A*; hence the bell will continue to ring, even after the button *P* is released, until the lever *L* is reset by pulling the cord *D*:

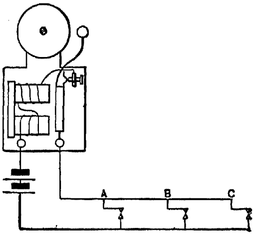

FIG. 140. A bell arranged to be rung from any of the stations *A*, *B* or *C*.

Example 3. How can a circuit be arranged so that a bell can be rung from any of 3 places?

The bell in Fig. 140 can be

rung from any of the stations, *A*, *B* or *C*. Either main line wire may consist of a "ground," such as a gas pipe, water pipe, etc.

Prob. 5-7. Draw the diagram of a bell with 3 terminals which can be used either as a single-stroke or as a vibrating-stroke bell. Show the battery connections.

Prob. 6-7. Make a diagram of a bell with continuous-ringing attachment, which can be used on the lighting circuit. Show the connections to the lighting circuit.

75. Buzzers. A buzzer is constructed like any of the bells described above. (See Fig. 134.) The clapper and bell are left off and the noise is made by the vibrating armature. A master buzzer is often used to operate a set of cheap bells. These bells must be of the single-stroke type arranged in series. The buzzer merely opens and closes the circuit and causes the bells to act as vibrating-stroke bells. This is a very handy arrangement, since the contact points on the buzzer are the only ones in the circuit to get out of order, and therefore the system is more easily kept in good condition.

Prob. 7-7. Draw the diagram of a buzzer operating 3 bells on a battery line. Include the complete electrical circuit.

Prob. 8-7. Draw a diagram of a buzzer to operate on a 110-volt line, ringing 2 bells. Put in the complete electrical circuit.

Prob. 9-7. Two or more circuit-breaking bells will not work well in series. Draw a diagram showing how a single-stroke bell can be used in series with a circuit-breaking bell.

Prob. 10-7. Draw a diagram showing how the combination bell in Prob. 5-7 can be rung from 2 stations; from one as a single stroke, from the other as a vibrating stroke.

76. Electric Door Opener. In apartment houses it is desirable to be able from each apartment to release the catch on the hall door. This is very easily accomplished by using the mechanism of a single-stroke bell, leaving the clapper and bell off. The movement of the armature, when the circuit is closed by pushing a button in any of the apart-

ments, releases a special lock and allows the door to be pushed open.

Prob. 11–7. Show the wiring diagram of an arrangement for ringing a bell in the apartment by a push button at the hall door, and for operating the hall-door opener from a push button in the apartment. Both are to use the same battery.

Prob. 12–7. Show the connections for wiring 4 bells and 1 battery so that 1 bell may be rung from any one of 3 stations, while the other 3 bells may be rung from a fourth station.

Prob. 13–7. Show the diagram for wiring the following:

Bell No. 1, to be rung from the front door push button.
Bell No. 2, " " " rear " " "
Buzzer, " " " dining room "

All bells are to ring by the same set of batteries.

Prob. 14–7. Show by a diagram a set of three bells which may be operated by one push button, and which may use current either from a set of cells or from the lighting circuit.

Prob. 15–7. Bells are often rung by two sets of storage batteries, one set being charged from the lighting circuit through lamp resistances, while the other is in service. Show a diagram for accomplishing this in such a way that the bell wiring is never connected to the lighting circuit, and therefore poorer insulation can be used on the bell circuit.

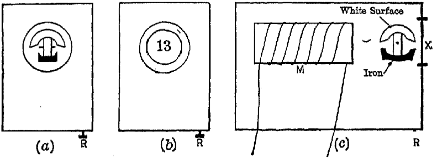

Fig. 141. An electric annunciator.

77. Annunciators. When several rooms are connected to a single bell, it is usual to put an annunciator in each circuit in order to tell from which place the call comes.

Fig. 141 (*a*) shows the appearance of the indicator when

it is idle. When it is tripped, a white ball, sometimes bearing a number, shows at the window, as in Fig. 141 (*b*). The mechanism is explained by Fig. 141 (*c*). The white surface is made of non-magnetic material, but is joined to a piece of iron *D* of crescent shape, and the whole is pivoted near the center. When a current goes through the coils of the magnet *M*, it attracts the crescent-shaped iron, and in drawing it nearer, turns the white surface out toward the window (*x*). The indicator is usually arranged to remain in this position, when once tripped, until it is released by the attendant who pushes the button *R*, which shoves the indicator back to the "idle" position. A desk annunciator is shown in Fig. 142.

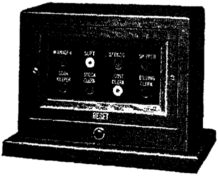

FIG. 142. A desk-type annunciator. *S. H. Couch Co., Inc.*

Another very common type of annunciator has small arrows, instead of the white surface; one arrow for each station. The "idle" position is with the arrow horizontal. When the bell is rung, the arrow indicating the calling station swings to a vertical position. It is brought back to the horizontal by pushing or pulling a lever.

By means of an annunciator box placed near the bell in Fig. 143 it is possible to tell from which of the three stations a call is coming.

In Fig. 144 is shown a return call annunciator system used in many hotels, where it is necessary for the guest to be able to ring up the desk, and for the desk to ring up the guest.

Prob. 16–7. Several patented systems are on the market which form very compact devices for accomplishing the results obtained by Fig. 144. They usually make use of 3-way push

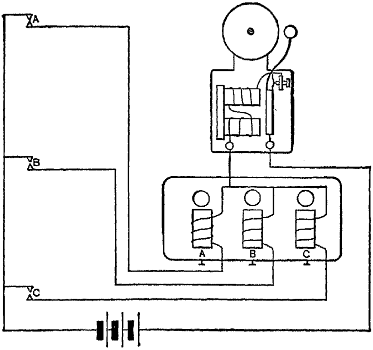

Fig. 143. A single bell with annunciator that indicates by which of the three stations A, B and C the bell is rung.

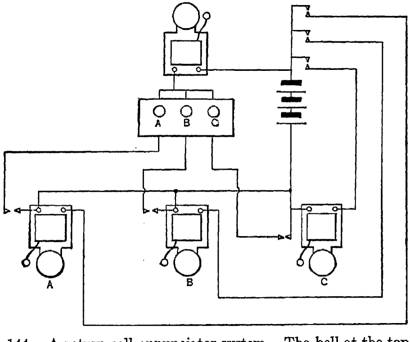

Fig. 144. A return-call annunciator system. The bell at the top can be rung from any of the three stations below at A, B and C.

buttons in place of the simple 2-way button of the illustrations. Draw a diagram showing typical wiring of one of these systems, using a 3-way push button or strap key, as shown in Fig. 145.

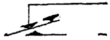

Fig. 145. A three-way push button or strap key.

78. Fire-alarm Systems. There are many systems for sending in fire alarms. They are all, however, arranged to sound continuous-ringing gongs at several places in the building, and most of them have an annunciator attachment showing the place from which the alarm was sent in. For simplicity, a system hav-

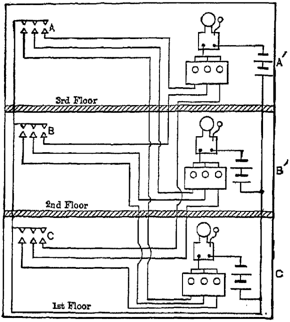

Fig. 146. Fire-alarm system. Three gongs and three stations.

ing but three gongs and three sending stations is shown in Fig. 146.

Note that wherever any one of the three switches *A*, *B* and *C* is thrown, it rings all three bells *A'*, *B'* and *C'*, and the annunciators at the bells indicate which switch is thrown. These switches can be thrown by hand or automatically by

means of a thermostat as in Fig. 147. The thermostat operates as follows: A strip of hard rubber is riveted to a steel spring which is fastened firmly to the support *P*. When heated, both steel and rubber expand, but rubber expands much more than steel. This causes the spring to bend or buckle and make an electrical contact at *G*. A current now flows through the relay and draws over the armature which releases the detent *T*, and allows the spring *S* to draw down the switch and close the circuit.

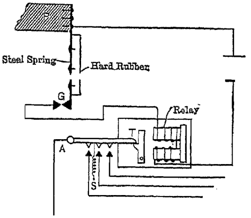

FIG. 147. A thermostat arranged for automatically sending in a fire alarm.

Special thermostat metal, consisting of a strip of brass brazed to a strip of steel, is often used, instead of the steel rubber combination.

Many other modifications of this system are in use, which make the entire action more certain, but they all work on the general principles illustrated.

Prob. 17–7. Show a diagram of connections for a fire-alarm system in which a whistle is blown by a relay operated by opening the circuit. The relay is normally energized by a closed-circuit battery.

Prob. 18–7. Show a scheme for a fire-alarm box which will open the circuit when a small pane of glass is broken.

79. Burglar Alarms. In order that the system may not be put out of order by the cutting of the wires, burglar alarms are generally of the closed-circuit type. A simple scheme of this kind is shown in Fig. 148. The battery *B* causes a current to flow through a circuit in series with the coils on the magnet *M* in the bell. This keeps the arma-

ture drawn over, leaving a break at *G*, so that battery *A* is not sending a current through the bell. But, as soon as the circuit containing battery *B* is broken, the armature springs back and is kept vibrating by battery *A*. The devices marked *C* and located at all windows, doors, sky-lights, etc., are often constructed on some modification of the device shown in Fig. 149 and are called "traps."

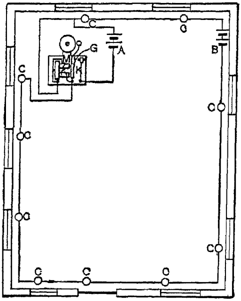

FIG. 148. Closed-circuit burglar alarm.

The switch *A* is held on the contact point *C* by the string *T* which pulls against the spring *S*. This string is fastened to the window or door. The contact is so delicate that if the string is pulled very slightly, the switch is moved from the contact point *C* and the main circuit is opened. The bell is thus set ringing, as explained above. If, on the other hand, the string is cut or slackened the least bit, the spring *S* pulls the switch away from the contact point in the other direction and opens the circuit.

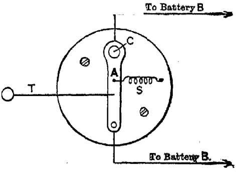

FIG. 149. Closed-circuit trap.

In an open-circuit system, a modification of this device is used as shown in Fig. 150. The slightest change in tension on the string *T* now closes the circuit, either on one button or the other.

Many other "traps" are made, which can be built into

the window sash or the door jamb or laid under the mat or the carpet. In many cases, each window and door has a separate circuit passing through an annunciator. Before setting the alarm for the night, the bell can be thrown out of the circuit and the annunciator used to locate any window or door which may not have been closed or locked.

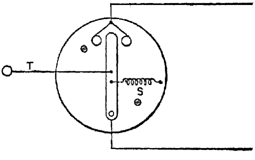

FIG. 150. Open-circuit trap.

Prob. 19–7. Make a diagram of a simple burglar-alarm system using the device of Fig. 150 for a "trap."

Prob. 20–7. Draw a diagram showing connections for an annuciator burglar alarm which rings a bell and indicates which of the doors of 3 stores is opened. The bell and annunciator are located in the owner's apartment above the group of stores.

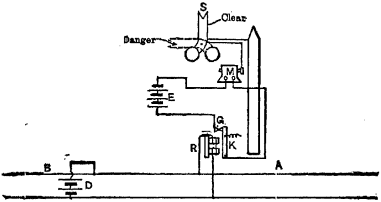

FIG. 151. Diagram of railroad block signal.

80. Railway Block Signals. For operating railway block signals, the track between two stations is divided into several sections, called **blocks**, which are separated from one another by an insulating space, as at A and B in Fig.

151. When the block is clear, a closed-circuit battery D at one end of the block sends a current through the coils of a relay situated at the other end, R, thus keeping the armature K in contact at G. But when the wheels of a car or engine enter the block, they make a short circuit through the axle from one track to the other around the relay and steal the current from the relay. Thus the spring is allowed to pull the armature K over, breaking the contact at G. This releases magnetically the pin, which is holding the semaphore S in the vertical or "clear" position, and allows a counterweight to pull it into the horizontal, or "danger," position, where it remains as long as there is a pair of wheels on the block. But when the last pair of wheels leaves the block, the battery D is again free to send a current through the relay R which pulls the armature K over and makes contact at G. The secondary battery E now drives the motor M, which is geared to the semaphore S. The semaphore is thus raised and locked at the vertical or "clear" position, and the motor automatically cut out. Note that an **open switch** or a **broken rail** will open the circuit in which the relay is connected and set the signal at "danger."

This is the simplest type of block signal. Many of the systems in use provide for an intermediate or 45° position of the semaphore when the train is in the next block ahead. The signal is thus at "danger" when there is a train on the block, and at "proceed slowly" when the train has passed into the next block ahead. The semaphore does not then become vertical, or "clear," until both the block itself and the one ahead are empty.

Daylight lamp signals are being installed in many sections of the country instead of semaphore signals.

Prob. 21-7. Make a wiring diagram for the 3-position semaphore signal system described above.

81. Railway Crossing Signals. Fig. 152 shows a modern grade-crossing signal which displays an illuminated "STOP" sign and a pair of alternately flashing lamps when a train is approaching from either direction. The series of diagrams in Fig. 153 shows the different stages in the operation of these signals. The insulated track sections A and B extend on either side of the crossing to the points where entering trains are to start the signals. When both sections A and B are clear, the batteries b and b' send currents through the rails and through the coils c and c' thus holding up the arms M and M' and keeping both switches K and K' open as shown in (*a*). When a train enters section A from the West, Fig. 153 (*b*), the current from battery b which would normally flow through coil c goes through the wheels and axles of the train allowing the electromagnet to become so weak that arm M drops down, closing the contact points at K and completing the circuit between f

Fig. 152. Modern grade-crossing signal. *Union Switch and Signal Co.*

and g. This circuit f–g contains the control switches for the STOP lamps and the flashing mechanism. Now when the train reaches the crossing and begins to cover both sections A

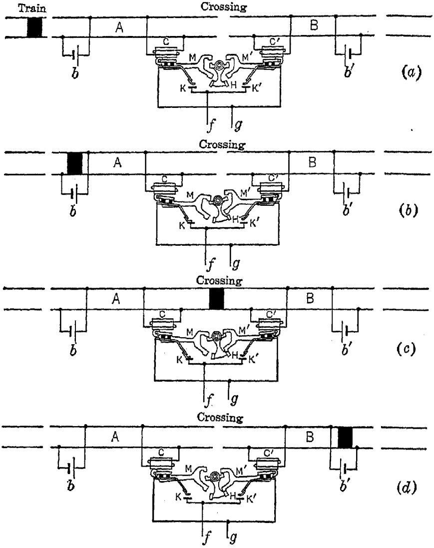

Fig. 153. Successive positions of interlocking relay during the operation of a railroad crossing signal.

and B, Fig. 153 (c), both electromagnets c and c' are weakened releasing arm M' as well as M. But note that due to the position of the pawl H, M' cannot fall far enough to

close switch K', so that when the last car of the train passes the crossing, electromagnet c is again energized drawing up arm M and opening points K. This opens circuit f–g and the signals cease to operate. Fig. 153 (d) shows how the pawl H continues to hold M' from closing K' until the train passes out of section B when electromagnet c' is again energized bringing the relay back to the condition shown in Fig. 153 (a). If the little mechanism H were not present it is easy to see that the signals would keep on operating for some time after the train passed the crossing.

There are several kinds of crossing signals, some having semaphores, some swinging arms, and some ringing gongs, but any of these types can be attached at f–g to the control circuit just described.

Prob. 22–7. Draw 4 sketches similar to those in Fig. 153 showing the sequence of operations in the interlocking relay when a train approaches the crossing from the East.

Prob. 23–7. Complete a circuit from terminals f–g showing how a relay similar to the one in Fig. 151 would close the switch to operate a motor-driven swinging arm signal.

82. Electric Track Switches. In Fig. 154 is shown the Cheatham track switch. It consists primarily of three elements: the **pan,** A, attached to the trolley wire about 30 feet from the switch; the **pole box,** B, containing the electromagnet (x) which makes the proper electric contact; and the **track box,** C, containing the electromagnets (1) and (2), which operate the track switch.

Note that the coil on the electromagnet (x) in the pole box is connected directly to the trolley wire at (a) and to the insulated strip (b), on the pan.

Suppose the motorman wishes to go to the right. He shuts off power and coasts across the pan. When the trolley wheel strikes the pan it **leaves the trolley wire** and **bridges the parallel strips** (b) and (d), thus connecting them elec-

trically. The current then flows from the trolley at (a) through the coil (x), to the strip (b), through the trolley wheel to the strip (d), down to arm V, through coil (y) to track magnet (1), and then to the ground. The total

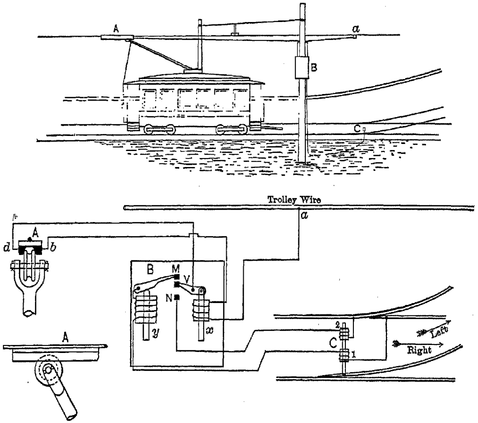

FIG. 154. Illustration and diagram of an electric track switch.

resistance of the three coils (x), (y) and (1) in this circuit is about 80 ohms. As the voltage is about 550 volts, the current must be $\frac{550}{80} = 7$ amperes (approx.). This small current has no effect upon the plunger in the coil (x), but is enough to actuate the plunger in the track coil (1) and set the switch to the **right**.

Coil (1) is not able to carry this current for more than a minute without heating. If the car should happen to stop

with the trolley wheel on the pan, the coil (*y*) is arranged so that a plunger rises very slowly in a dash pot and breaks the contact at *M*, thus saving coil (1) from burning out. The coil (*y*) thus plays no part in setting the switch. It merely acts as a circuit breaker in case of a long-continued current through coil (1).

If the motorman wishes to go to the left, he throws the controller handle over two or three notches. The current then enters at (*a*) and goes through coil (*x*) to strip (*b*) as before. But, since the motorman has turned on the power, a current can flow from the strip (*b*), through the trolley wheel, through the car motor to the ground. The resistance of this path is so low that about 30 amperes flow. This current is enough to pull up the plunger in the coil (*x*), and trip the arm *V* so that it breaks the contact at *M* and makes a contact at *N*. The current now comes from the trolley at (*a*), goes through the coil (*x*) to the strip (*b*), crosses, by means of the trolley wheel, to the strip (*d*), goes to the arm *V*, through the contact *N* down to track magnet (2) and operates the plunger which sets the switch to the left.

During this process the coil (*x*) is carrying a large current, because it carries both the current which is allowed to go through the car motor and also the current which crosses over to the strip (*d*) and operates the switch. But as soon as the trolley wheel leaves the pan, and thus no longer bridges the strips (*b*) and (*d*), the circuit is open at this place and no current flows through the coil (*x*). The plunger therefore drops and sets the arm *V* back into contact with *M*, so that the next car can go either to the left or to the right. The switch, however, always remains set in the direction in which the car last passing left it.

Combinations of relays, motors and mechanisms called switch machines are in use in nearly all the large railroad

yards for operating track switches and indicating which way the switch is set. Fig. 155 shows one of these devices.

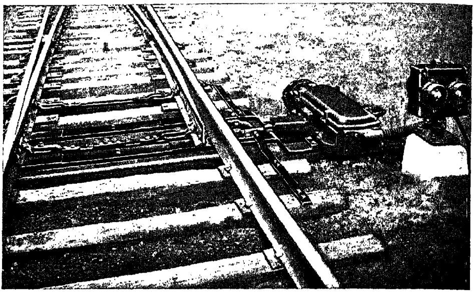

FIG. 155. Automatic track-switch machine. *General Railway Signal Co.*

83. Temperature-control Devices. Several kinds of devices for automatically controlling gas- or oil-burning furnaces or for opening and closing drafts of coal-burning fur-

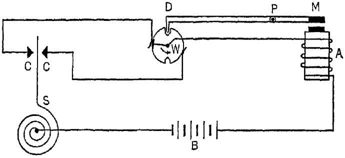

FIG. 156. Control mechanism of electro-mechanical furnace regulator.

naces are on the market. Fig. 156 shows a circuit in which a spring motor is electrically controlled by means of a thermostat.

The thermostat spring S is so constructed that it will move its arm to the right when heated and to the left when cooled. By setting the pair of contacts C–C to the right or left, the temperature at which the room is to be kept may be changed as desired. The wheel W is a combination electric switch and motor controller allowing the motor to run while the wheel makes one half revolution after being released by detent D and until caught again in the opposite slot. In the case of a coal-furnace control, the motor is able, during the half revolution of W, to open the base draft and close the cold-air draft, reversing these operations during the next half revolution of W.

Suppose the temperature has just dropped below that for which the contacts C–C are set. Spring S will make contact with the left-hand point, completing the battery circuit through the electric switch on wheel W, thus sending a current through the coil of electromagnet A. When A is energized, it pulls down arm M of the iron bar pivoted at P thus releasing wheel W which now allows the spring motor to run until detent D catches W in the opposite notch, at the same time breaking the left-hand switch contact and making the right-hand one. The battery circuit now remains open at C until the room is warm enough to move the thermostat arm S to the right.

Prob. 24–7. Show by a sketch how a thermostat may be made to control the temperature of an electric oven through a relay.

84. The Induction Coil. When a current is sent through a coil of wire wound on an iron core, a magnetic flux is set up in the core as we have seen. Now during the time when this flux is changing, a voltage is set up or induced in the coil, and the size of this voltage depends not upon the amount of flux but upon how fast it changes. If it changes from zero to a certain value in 0.01 second, it will produce ten times

as much voltage, on the average while the flux is changing, as it would if it made this same change in 0.1 second. It will produce the same amount of voltage whether the flux is increasing or decreasing.

The size of the voltage produced depends also upon the number of turns in the coil. That is, a certain rate of change of flux will produce five times as many volts in 500 turns as it will produce in 100 turns.

At the instant of closing points *P*, Fig. 157, a current starts setting up flux in the coil. The flux rises to a steady value in a fraction of a second and while it is doing this a varying voltage, at first equal to that of the battery but dying away to zero, is induced by the changing flux.

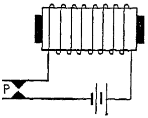

FIG. 157. Induction coil and circuit.

When the points *P* are opened, however, the flux changes from its former steady value to zero in a very small fraction of a second and induces in the coil a voltage which may reach many times that of the battery. Thus if a person takes hold of the contacts *P* while he closes them he feels no shock, but if he retains hold when he opens them he gets a painful jolt. This electric shock is due to the high voltage impressed across the human body during the brief period of flux change. In small " shocking coils " of this type there is usually not enough energy available to do any physical harm even though the voltage impressed may rise for an instant to several thousand volts, but such voltages would be fatal if sustained for any considerable time.

When the points *P* are opened, a spark will jump across them due to the high voltage induced. This spark is sometimes used to ignite illuminating gas or the gas mixture inside the cylinder of a gasoline engine. For the latter purpose, however, another type of coil shown in Fig. 158

is more commonly used. In case the scheme of Fig. 157 is used, the points *P* have to be right inside the engine cylinder.

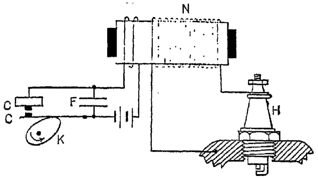

FIG. 158. Circuit of make-and-break gas-engine ignition system.

85. Gas-engine Ignition. The circuit of a **make-and-break** system of gas-engine ignition for a one-cylinder engine is shown in Fig. 158. The cam *K* is so geared to the main shaft of the engine that it opens the contacts *C–C* at the instant when conditions in the cylinder are just right for ignition. During the period in which the contacts *C–C* are closed, the battery sends a current through the iron-cored coil *M* (called the primary coil) setting up a flux in the iron core. When this flux changes it induces a voltage both in itself and in the other coil *N* (called the secondary coil) wound on the same core. Now coil *N* is composed of many turns of fine wire and has induced in it many times the voltage induced in *M*. When the circuit through *M* is broken, this high voltage induced in *N* is sufficient to send a spark across the gap between the points of the spark plug *H*. The condenser *F* steals the current away from contacts *C–C* when they open, thus preventing burning them.

For automobile ignition, the arrangement of Fig. 158 is modified by providing a vibrator to open and close the points *C–C* in rapid succession thus giving a series of sparks rather than a single one. This is accomplished by placing the vibrating points at the end of the induction coil thus using

the magnetism of the core to draw the points apart. The time at which the spark is started and the length of its period are controlled by a device called a timer which closes

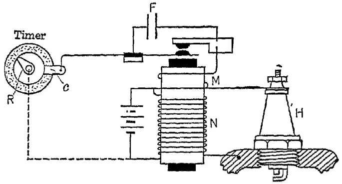

FIG. 159. Circuit of jump-spark gas-engine ignition system.

the circuit during a certain part of the cycle. Fig. 159 shows a diagram of the complete circuit for a one-cylinder engine.

86. The Control of Incandescent Lamps. Fig. 160 represents the ordinary wiring of a lamp when it is desired to turn it off or on from a single wall switch.

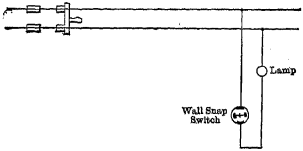

FIG. 160. The lamp is controlled from a single wall switch.

If it is desired to turn a lamp on or off at one station, as at *A*, and also at another station *B*, regardless of how the switch is set at the other station, the wiring may be done as in Fig. 161.

Fig. 162 shows the method of control from any number of points, since any number of 4-point snap switches such

as B, C and D, can be inserted between the 3-way switches A and E if more points of control are needed.

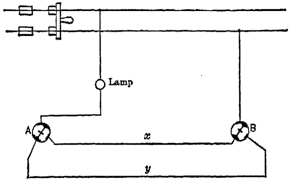

FIG. 161. The lamp may be turned off or on from either switch A or switch B.

Lighting systems in halls and lecture rooms often require the control of a large number of lamps from two or more points. Even when they are controlled from a single point,

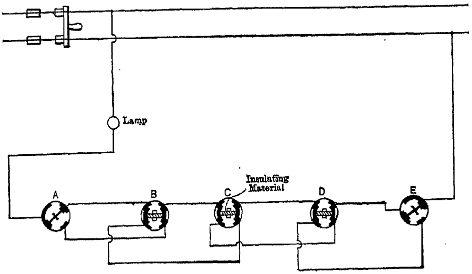

FIG. 162. The lamp may be turned off or on from any of the five points A, B, C, D, E.

the ordinary push-button or snap switches cannot carry the excessive load. In such cases, a small single-pole switch

is made to control a relay which in turn operates a heavy, usually double-pole, switch.

Fig. 163 shows a single-pole snap switch S connected to the electromagnet M in such a way that when this small switch is closed, plunger H is pulled down against the action of coiled spring K causing the heavy switch blades A to make contact with terminals C. When switch S is opened, electromagnet M loses its force and allows coil spring K to open the switch. Another type of heavy-duty remote-control switch has a mechanical locking device which holds the switch closed and also opens the control circuit in order that the coils of the electromagnet may not be required to carry current all the time the lamp load is in use.

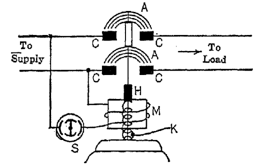

FIG. 163. Snap switch controlling large magnetic switch.

Prob. 25–7. Show a diagram of connections for the control of all the lamps in a motion-picture theatre. Use one heavy-duty magnetically-controlled switch and two 3-way switches, one in the motion-picture booth and the other on the stage.

Prob. 26–7. Draw a diagram showing the control of an incandescent lamp from 2 points both near the main line. The lamp is to be placed in a single line between the double points of the switches and the remaining terminals of both switches are to be connected to the line wires. Note: This connection, although it will properly control the lamp, is not permitted by the National Electric Code (See Rule 1204b) since in this case both poles of the circuit are connected to the switch.

Prob. 27–7. Could you arrange the 5 switches of Fig. 161 in a different way and still control a single lamp from 5 points? Does your arrangement meet the requirement of the National

Electric Code that "only one pole of the circuit will be carried to the switch"?

87. Electric Signs. With the advent of the low-voltage tungsten lamp, a number of which can be used in series on a standard voltage line, the cost of display illumination has been greatly lowered. Consequently this branch of electric lighting has become very popular and many brilliant and striking effects are produced.

Fig. 164 shows a mechanism for producing so-called **flashing signs.** By means of a motor connected through the

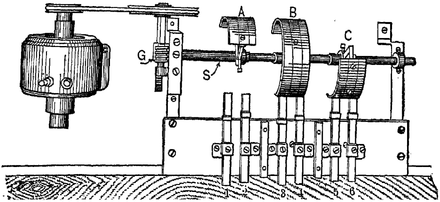

FIG. 164. Sign flasher.

gears *G*, the shaft *S* is made to turn slowly. The circuit through the lamps in one part of the sign is brought to the brushes (1) and (2). As the shaft turns, the brass or copper arc *A* comes momentarily into contact with these two brushes and this set of lamps flashes up. As soon as the arc *A* leaves these brushes, of course this set of lamps goes out. Similarly, other sets of lamps, connected through brushes (3) and (4) and (5) and (6), are flashed on and off by the arcs *B* and *C*. By changing the relative positions on the shaft of the arcs *A*, *B* and *C*, any desired change in the time and sequence of the flashing of each set of lamps can be made. Thus all the lamps may flash at once and go out at once. One may flash just as another goes out, or they may flash one after

SUMMARY OF CHAPTER VII

AN ELECTROMAGNET consists of many turns of insulated wire wound on a soft iron core. When electric current flows in the coil of wire, magnetic flux is set up in the iron.

The MAGNETOMOTIVE FORCE or cause of magnetic flux in an electromagnet depends upon the current and the number of turns in the coil. It may be measured in units called ampere-turns, found by multiplying the amperes times the turns.

A PERMANENT MAGNET is made by placing hard steel inside a coil of many turns carrying a large current.

Many signaling, communication and industrial control devices depend upon magnets for their action. Some of these, electric bells, buzzers, annunciators, door openers, fire and burglar alarm systems, railway block and crossing signals, railway track switches, temperature-control devices, gas-engine ignition systems and remote-control switches are described in detail in this chapter.

PROBLEMS ON CHAPTER VII

Prob. 31–7. A certain single-stroke electric bell has 200 feet of No. 32 copper magnet wire wound in 1000 turns on its electromagnets. What current flows through its coils when connected to a 6-volt storage battery? What is the magnetomotive force under these conditions?

Prob. 32–7. What would the magnetomotive force be in the coils of the bell of Prob. 31–7 if an 8-volt battery were used? How many times as strong is the magnetomotive force with the 8-volt battery as it is with the 6-volt battery?

Prob. 33–7. A certain generator has field windings of 2000 turns per pair of poles. What is the field magnetomotive force of this generator per pair of poles when the field current is 0.70 ampere?

Prob. 34–7. A certain shunt motor has 800 turns per pair of poles in its field winding. What is the field magnetomotive force when the field current is 3.2 amperes?

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Prob. 34-7. A certain shunt motor has 800 turns per pair of poles in its field winding. What is the field magnetomotive force when the field current is 3.2 amperes?

Prob. 35–7. Show a diagram of connections for a single-stroke-bell janitor-call system in which 5 bells on different floors of an apartment house are rung from a single push button in the head janitor's office.

Prob. 36–7. Show by a diagram how a return-call signal system can be installed connecting two stations having only a single pair of wires between them. Either station is to be able to signal the other.

Prob. 37–7. Show a diagram of a device which will ring a bell when the water in a cistern rises to a specified level.

Prob. 38–7. Give a diagram of connections of a door-opening signal for a country grocery store. When the door opens a bell is to ring in the kitchen to indicate the entrance of a customer.

Prob. 39–7. Through how many feet of No. 18 annunciator wire can an electric bell requiring 0.5 ampere be rung from a 6-volt storage battery?

Prob. 40–7. If the vibrating bell shown in Fig. 136 will operate successfully on not less than 4 dry cells, how could you reconnect its coils to make it operate as well on 2 dry cells as it formerly did on 4?

Prob. 41–7. An electric gong taking 5 amperes to operate is to be controlled by a push button 1000 feet away. Draw a diagram showing the circuit if the power is supplied from a storage battery near the push button.

Prob. 42–7. The electric gong of Prob. 41–7 takes 5 amperes at 15 volts to operate. (*a*) What power is used in operating the bell? (*b*) What power is lost in the line wires if No. 18 copper wire is used? (*c*) What power is lost in the line wires if No. 14 wire is used? (*d*) What voltages would be required for the battery in parts (*b*) and (*c*)? Would there be any saving of power if the battery were placed near the gong rather than near the push button?

Prob. 43–7. Evidently from the results of Prob. 42–7, the power lost in the line is much greater than that used in ringing the gong. Draw a diagram of connections using a sensitive relay similar to the one in Fig. 151 to control the circuit through the gong. What voltage must the battery have in this case? The local circuit through the gong contains 25 feet of No. 14 copper connecting wire.

CHAPTER VIII

ELECTRICAL COMMUNICATION SYSTEMS

The electrical transmission of messages is made possible through the development of such communication instruments as the telegraph and the telephone. Both of these devices have become so extensively used that it is now possible, through a vast network of wires covering the civilized world and with the help of long-distance radio links, to telegraph or telephone to almost any desired point.

The **telegraph** transmits messages by means of impulses of electric current sent over the wires. A simple buzzer and push button circuit may be considered as an elementary telegraph system. While the button is held down the buzzer will operate; otherwise it will be silent. If now we agree that a short buzz shall indicate the letter *E*, a long buzz the letter *T* and a short, a long and two short buzzes the letter *L*, we can send the word "TELL" over our elementary telegraph system by making first a long buzz, then a short buzz, then a short, a long and two short buzzes, and finally a short, a long and two short buzzes. Thus we see that before telegraphing a message it must first be translated into a code. The Continental Code much used in radio work is as follows:

A ·–	B –···	C –·–·	D –··	E ·	F ··–·
G ––·	H ····	I ··	J ·–––	K –·–	L ·–··
M ––	N –·	O –––	P ·––·	Q ––·–	R ·–·
S ···	T –	U ··–	V ···–	W ·––	X –··–
Y –·––	Z ––··				

1 ·––––	2 ··–––	3 ···––	4 ····–	5 ·····
6 –····	7 ––···	8 –––··	9 ––––·	0 –––––

CHAPTER VIII

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G ––·	H ····	I ··	J ·–––	K –·–	L ·–··
M ––	N –·	O –––	P ·––·	Q ––·–	R ·–·
S ···	T –	U ··–	V ···–	W ·––	X –··–
Y –·––	Z ––··				

1 ·––––	2 ··–––	3 ···––	4 ····–	5 ·····
6 –····	7 ––···	8 –––··	9 ––––·	0 –––––

In the early days of telegraphy the messages were all coded as they were sent by one operator and decoded as received by a second operator. The more recent printer telegraphs make it unnecessary for the operator of these instruments to know the code since the coding is done automatically.

The **telephone** has become a common household necessity, its purpose being, of course, to transmit speech or radio broadcast programs with a satisfactory degree of fidelity.

The vacuum tube has had its first and most extensive use in the field of communication and is indispensable in long-distance wire and radio systems. In order to understand the action of telephone and telegraph repeaters and radio transmitters and receivers, it will be necessary to study the principles upon which the vacuum tube operates.

Prob. 1–8. Translate your name into the Continental Code.

88. The Telegraph. The following paragraphs on the telegraph and the telephone are not intended to serve as wiring instructions for installing these devices, but merely as an explanation of the principles upon which they operate. The modern uses of these two devices are very extensive and the circuits are very complicated, and for this reason the treatment here is of necessity elementary.

In Fig. 165 is shown a telegraph system with two stations. A large number of stations may be arranged in series on a single line. Note that there is a local circuit at each station and a main circuit between stations. The main circuit is closed when the line is not in use. This holds down the armatures N and N_1 of the local circuits. The batteries on the main line must be of the closed-circuit type to prevent their running down.

Suppose station A wishes to send a message to B. The short-circuiting switch S is opened and the main line is thus opened. This releases the armature on the relays R and R_1, because the main current is broken. These relays

are similar to the magnet and vibrator in an electric bell, but they are much more delicate so that a minute current will operate them. They are used merely to open and close the local circuits. When any key, for example the one at A, is up, the spring pulls up the released relay armatures N and N_1 and closes the local circuits so that the sounders X and X_1 attract their armatures, making the peculiar click-

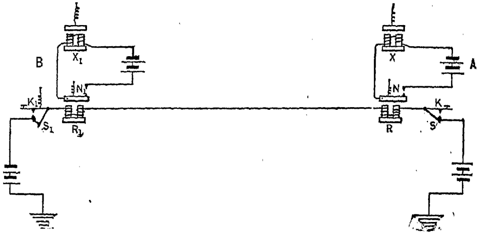

FIG. 165. Diagram of a telegraph line.

ing sound which is heard in a telegraph office. Now when A presses down his key K again, the armatures of both relays are drawn down, opening the local circuits. The springs on the armatures of the sounders X and X_1 now draw these up and produce another click. Every time the key K is released or pressed down, all the relays on the line move and actuate the armatures of the sounders in all the local circuits. At most stations, cut-out switches are arranged in the local circuits so that only the sounder of the station called is allowed to click. The so-called "dots and dashes" are produced by varying the length of time between clicks; the time for the dashes being slightly longer than that for the dots. When the line is not being used all instruments are left in service in order to receive the "calling signal."

In the system pictured here a galvanized iron wire may be used for one side of the line, the " return " side of the circuit being through the ground. A large part of the telegraph traffic is now carried over lines which carry telephone messages as well. (See Fig. 167.)

Prob. 2–8. A standard telegraph sounder has 5 ohms resistance. The local circuit is wired with 120 ft. of No. 22, B. & S., copper wire. The local battery cell has an e.m.f. of 1.08 volts and an internal resistance of 3 ohms. What current passes through the local circuit every time the sounder acts?

Prob. 3–8. A 15-mile telegraph line using the ground for a return has 3 relays of 20 ohms each connected in it. The line is operated by 10 cells in series, each having an e.m.f. of 1.07 volts and 2.8 ohms internal resistance. The line wire is the best grade of galvanized iron 165 mils in diameter with a resistance per mil-foot of 69 ohms. What current flows through this line when no message is being sent?

Prob. 4–8. What current flows through a 40-mile telegraph line when no message is being sent, if the line wire is of second-grade galvanized iron, 203 mils in diameter and with a mil-foot resistance of 81 ohms? The battery consists of 20 cells in series, each cell having an e.m.f. of 1.06 volts and an internal resistance of 3 ohms. There are 4 relays of 50 ohms each on the line, and the return is through the ground.

Prob. 5–8. When telegraph stations are widely separated, it is difficult to get strong enough currents over the whole length of line to actuate the instruments. In such cases, " repeaters " are placed at intermediate points. These are simply relays which operate additional sending keys. Show a 1-way telegraph circuit with a repeater halfway between stations.

89. The Telephone. A large bell when struck a hard blow will vibrate with such a force that the motion can be easily felt if the fingers are held on the surface. Piano or harp strings, especially the large ones which produce the low tones, vibrate with such amplitude that the motions can easily be seen. Such vibrating bodies are the causes of sound, the size of the vibration determining the loudness of

the sound and the **number of vibrations per second** determining its **pitch**. Thus, the musical note "middle C" is produced when a piano or violin string makes 256 vibrations per second.

This to-and-fro motion of strings, bells and reeds of musical instruments and of the vocal cords is imparted to the surrounding air and transmitted by means of air waves to the ear the drum of which is caused to vibrate with the same frequency as that of the body producing the sound. The telephone system, then, coming as it does between the source of the sound and the ear must change these sound waves into waves of electric current at the transmitter and then change the electric current waves back into sound waves at the receiver.

The way these changes are accomplished can be best understood by reference to Fig. 166.

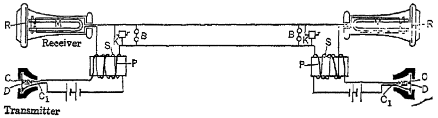

Fig. 166. Diagram of a telephone line.

The transmitter of a telephone system consists of a thin metal disk D, to which is attached a carbon button C. Between this button and another carbon button C_1 are small particles of loose carbon. When one speaks into the transmitter, the vibrations in the air cause the disk D to vibrate very slightly, not even enough to be seen, but still enough to keep varying the pressure on the carbon particles between the buttons.

Now, when the pressure between two pieces of carbon changes, the electrical resistance between them changes — the more pressure, the less resistance. Thus, when one

each station has a transmitter, receiver, magneto, bell and induction coil.

As the wiring schemes for telephone systems are very numerous and complicated, one simple plan only is outlined. The same principles, however, underlie all the systems.

The large city telephone systems employ a somewhat different circuit which allows the power for the transmitter circuits to be supplied from the central exchange thus eliminating the necessity for maintaining dry cells at each subscriber's station.

The telephone exchange or "central" is an office where the individual lines terminate and from which any one of a large number of subscribers can be reached. The circuits are so arranged that when a subscriber lifts his receiver, a lamp is lighted on a panel in front of the exchange operator. At this signal the operator connects her set with the calling party and, upon learning the number of the party called, completes the connection between the two subscribers. In the large cities, this manual exchange is replaced by an automatic or "machine switching" exchange. It is in connection with such exchanges that dial telephones are used.

Prob. 6–8. Add to the circuit of Fig. 166 a switch in each transmitter circuit to open the local battery circuit thus conserving the batteries when the receiver is hanging in its usual position. This switch must close, of course, when the receiver is lifted.

Prob. 7–8. Show a diagram of a 3-party telephone line terminating in a central office.

90. Combination Telephone and Telegraph Systems. A simplified circuit showing how a telegraph message can be sent over a telephone line is shown in Fig. 167. When a telegraph message is sent it must not disturb the telephone circuits. This requirement is effected by using both telephone wires for one side of the telegraph circuit and the

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ground for return. Notice that the telegraph connections are tapped in at the mid-points of the secondary coils, thus dividing the telegraph currents between the two halves of the winding. Since these halves of the current produce

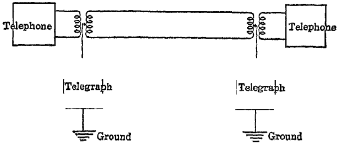

FIG. 167. Telephone circuit combined with a telegraph circuit.

magnetomotive forces in opposite directions, there will be no resultant electromagnetic effect on the telephone circuit (See Fig. 168).

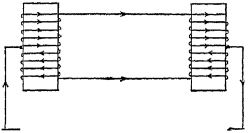

FIG. 168. Two secondary coils and connecting telephone line showing how a telegraph current introduced at the middle of each winding produces an equal number of ampere-turns in each direction and therefore does not disturb the telephone conversation.

Prob. 8–8. Show a telegraph circuit using 2 telephone circuits rather than 1 telephone circuit and ground.

91. The Nature of Electricity. Before we can study intelligently the action of vacuum tubes we shall have to get a picture of what happens when an electric current flows. It will prove interesting at this point to ask whether there is any way of seeing with the mind's eye what happens when electricity flows in a wire or when it flows through space as

it does in a vacuum tube. In Chapter I, we said we may think of definite amounts of electricity (measured in coulombs) just as we can think of definite amounts of water (measured in gallons). Now if the unit of measure (gallon) of water is subdivided into quarts, pints, gills, etc., a final unit (the molecule) of water is reached which is the smallest quantity of water it is possible to get. Similarly, if the unit of measure (the coulomb) of electricity is divided into 6,300,-000,000,000,000,000 equal parts (in round numbers), each one of these parts would represent the smallest quantity of electricity it is possible to get, and this smallest unit is called the **electron.**

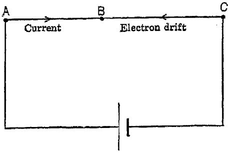

FIG. 169. The electrons actually flow from right to left. The electric current is said to flow from left to right.

All material substances are supposed to be made of these electrons and certain other much heavier units called protons. The protons carry positive charges and appear to hold a certain number of electrons (each of which is negative) in very intimate and jealous relationship while they do not seem so much interested in other electrons, allowing them to visit other protons if they can be influenced to do so. These visiting electrons are called "free" electrons and the electric current is made up of such roaming particles, which actually travel in the direction opposite to that which we have been using for current. Thus, in Fig. 169, point A is positive (+) with respect to B and will influence free electrons between A and B to move toward A. Also, between B and C, free electrons will be influenced to move toward B because B is positive with respect to C. It is, of course, confusing to try to think of this electron drift in the direction CBA as the same thing as our previous concept of current in the direc-

tion ABC, but this inconsistency is due to the fact that the real nature of the electric current was not understood until after the current had been thought for many years to flow the other way.

92. Insulators and Conductors. Much as in a water pipe plugged tightly with steel wool, particles of water would be held in the little chambers among the fibers, making the flow of water through the pipe difficult, many materials like glass and procelain at ordinary temperatures have the greater part of their electrons held in bondage by the protons, making the flow of electricity through them difficult. These materials having relatively few free electrons (and through which electricity flows with great difficulty) are classed as as insulators, and those substances having relatively many free electons (and through which electricity flows with ease) are classed as conductors. The insulators have high resistance while the conductors have low resistance.

93. The Two-Electrode Vacuum Tube. When one of these electrical conductors such as a tungsten wire is heated, electrons boil off its surface much as steam boils from the surface of hot water. In the latter case, if the receptacle containing the hot water is entirely closed so that none of the steam can escape, the particles will have to return to the water. If, on the other hand, a pipe allows the particles of steam to escape from the chamber as fast as they are boiled off, a current of steam continually flows from the surface of the water. In a very similar way, a filament F, Fig. 170, heated by an electric current from battery A boils off electrons into the surrounding space and if these are not removed from the vicinity of the filament, the greater number of these negative particles of electricity return to the filament. If, on the other hand, a plate P is brought near the filament

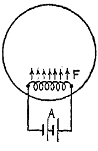

FIG. 170. Electrons are boiled off the surface of a heated filament.

as in Fig. 171 and is kept positively charged by means of battery B, then the negative electrons boiled off the filament will be attracted away by the positive charge on the plate and an electron current will be established in the direction indicated by the arrows. We have already mentioned that the conventional electric current, which is physically the same thing as the electron current, is considered as flowing in the opposite direction.

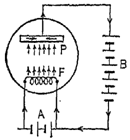

FIG. 171. Plate P, carrying a positive charge, attracts the electrons which leave the surface of the filament.

Let us see what happens if we reverse the direction of the "B" battery. This puts a negative charge on plate P and this negative charge repels the negative electrons thus driving them back toward the filament as they are boiled off. We cannot, therefore, have a current through the B battery circuit at all under these conditions.

One of the principal applications of the two-electrode tube just described is in the charging of storage batteries from an alternating-current source. Fig. 172 shows how one of these tubes is used in such a charging circuit. P represents the primary winding of an alternating-current transformer and since the current in it flows first in one direction and then in the other, a changing flux is set up in the iron core. Windings L and S, wound on this same core, have an alternating voltage, that is, a voltage first in one direction and then in the other, induced in them after much the same principle as explained in connection with the induction coil. Winding L is utilized as a source of current to heat the tube filament while winding S is the secondary used to supply charging

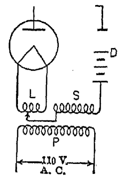

FIG. 172. Two element vacuum tube in battery-charging circuit.

current for the storage battery D. During the time when the voltage of S is positive toward the right it makes the plate of the tube positive if this voltage is greater than that of the battery, and a current of electrons leaves the filament and, jumping over to the plate, flows through the battery in the correct direction to charge it. During the periods when the voltage of S toward the right is negative the plate of the tube is negative and no current can flow through the battery circuit. Thus the tube acts like an electrical valve and it is sometimes called by this name.

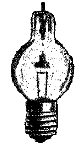

FIG. 173. Tungar rectifier tube. *General Electric Co.*

Tubes for this purpose are filled with some kind of gas inside instead of being highly evacuated. This makes it possible for them to carry heavier currents at lower voltages across the tube. A Tungar tube is shown in Fig. 173 and the complete rectifier with tube in place in Fig. 174.

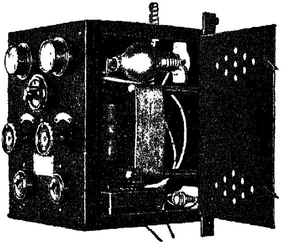

FIG. 174. A large battery-charging unit showing a tube in place. *General Electric Co.*

Prob. 9–8. Show the diagram of a circuit using 2 Tungar tubes in order to make the charger work during the periods which would be idle in a charger like the one of Fig. 172.

94. The Three-Electrode Vacuum Tube. Building upon our description of the two-electrode tube, let us see what happens if a "grid" G composed of fine wires is placed between the filament F and the plate P. If this grid is not connected to anything the action is much the same as before; but suppose we connect another battery, called a "C" battery, between the filament and the grid as shown in Fig. 175. This puts a negative charge on the grid while a positive charge is still maintained on the plate by the B battery. But the grid is nearer to the filament than is the plate and will for this reason have a much greater effect on the flow of electrons than the plate will. For example, if we change the grid voltage a certain amount, we may change the electron flow 5 or 6 times as much as would be produced by an equal change in plate voltage. Moreover since the grid is negative, there is practically no current in the grid circuit. Small changes of grid voltage with practically no current are thus made to produce corresponding large changes of plate current.

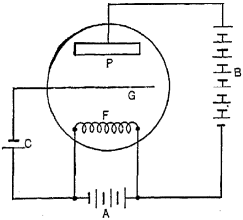

Fig. 175. Three-element vacuum tube showing battery connections.

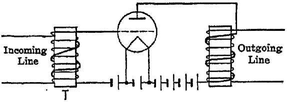

Fig. 176. Telephone amplifier.

Consider the elementary telephone amplifier shown in Fig. 176. A very faint telephone current is flowing in the

incoming line. This small current, changing direction the same number of times per second as the voice waves which caused it, flows through the primary of transformer T, producing a magnetomotive force, which in turn produces a changing flux, the variation of which induces a changing voltage still of the original frequency in the secondary winding. It is this changing voltage which is impressed on the grid terminals of the tube and which causes large corresponding changes in the plate current. This strengthened or "amplified" current is now strong enough to carry the signal a long distance. Or, as shown in the diagram, the output energy may be passed through another transformer to raise the voltage before it goes on its way from this repeater station.

Three-electrode vacuum tubes are used for three purposes in communication circuits:

1. To produce high-frequency alternating currents (generator).
2. To separate the audio- or voice-frequency wave from the high-frequency carrier wave (detector).
3. To amplify signals (amplifier).

The first of these actions is employed in producing the high-frequency carrier waves in radio transmission. The second will be explained in the next section and we have already considered the third.

Prob. 10–8. Insert the telephone repeater shown in Fig. 176 into a 1-way telephone circuit between 2 distant stations.

95. Radio Telephony. When a program is broadcast from one of the many broadcasting stations, the sound waves are introduced into the local electric circuit in the same way as in wire telephony, that is, by setting up electric currents corresponding to the sound waves in size and frequency. From this point, however, the mechanism is different. A vacuum-tube circuit is provided for generating high-fre-

quency alternating currents which, when introduced into an antenna circuit send out electromagnetic and electrostatic waves in all directions. By placing a coil carrying the voice- or "audio"-frequency currents near one carrying the high- or "radio"-frequency currents, the latter are varied by the inductive effect of the former and the electromagnetic waves

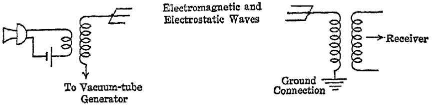

FIG. 177. Showing how the voice waves are combined with high-frequency waves before broadcasting.

go out as a mixture of the audio- and radio-frequency waves. (See Fig. 177.)

At the receiving station, the problem is threefold:

1. To change the electromagnetic waves back into electric currents.

2. To separate the audio-frequency from the radio-frequency currents.

3. To magnify or amplify these currents enough to operate a telephone receiver or a loudspeaker.

The first of these is accomplished by providing a receiving antenna circuit in which the electromagnetic waves may induce electric currents. The second part of the problem is solved by the use of a vacuum tube used as a detector and the third by a vacuum tube used as an amplifier.

A simple but effective receiving set is shown in Fig. 178. The electromagnetic waves in the neighborhood of the antenna circuit induce electric currents which flow through the primary coil P of a "coupling transformer." These currents, again by induction, produce voltages in the secondary coil S of this same coupling transformer and since this coil is a part of the grid circuit of the vacuum tube these

voltages are impressed between grid and filament. In this case the tube performs the double function of detection and amplification, the currents passing through the telephone

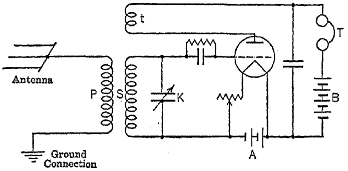

FIG. 178. Single-tube radio-telephone receiver.

receivers T being similar to those received in a wire telephone system.

The detector action of the tube is as follows. As we have seen, the incoming wave is a combination of a high-frequency wave Fig. 179 (*a*) and a low-frequency wave (*b*) resulting in a composite wave (*c*). The detector, in performing its function, must give us back a wave like (*b*).

Now the incoming wave (*c*) has successive alternations which run as much above the horizontal axis as they do below; that is, f is as far above as g is below. The detector action of the tube is such that the increases of voltage, like f, impressed on the grid terminals, Fig. 178, produce greater increases in plate current than the decreases like g produce decreases in plate current, resulting in a wave of the form shown in Fig. 179 (*d*). The average of this distorted wave is shown by the dotted curve and is of the same shape as the audio-frequency wave (*b*). Thus there exists in the output current of the tube a component which causes the receiver diaphragm to vibrate with the same frequency as that of the telephone transmitter diaphragm.

In the circuit shown in Fig. 178 further amplification is

produced by feeding some of the wave shown in Fig. 179 (*d*) back into the grid circuit by means of the " tickler " coil *t*.

Now how do we make the receiving set select the program from a particular sending station? The answer to this question is that each sending station in a given part of the

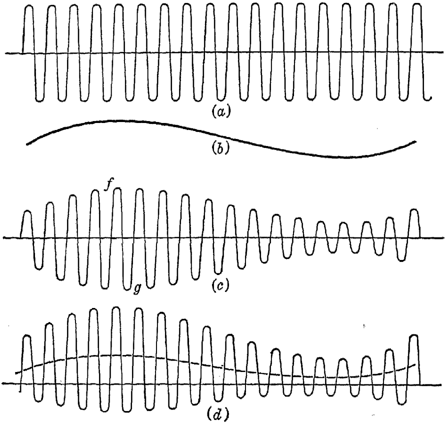

FIG. 179. (*a*) The radio-frequency waves. (*b*) The speech-frequency waves. (*c*) Combination waves (*a*) and (*b*). (*d*) Rectified waves showing speech-frequency component.

country is assigned a given **frequency**, that is, **number of waves per second** which it must use for its radio-frequency or " carrier-wave " system. When we decide that we desire the program of a certain station within the receiving range of our set, we proceed to make our set receive the frequency of the desired station better than it can receive the frequency

of any other station. This process is called **tuning** and it consists of making it easier for currents of the desired frequency to flow in the circuits of the set than for currents of any other frequency. The variable condenser K may be placed at such a setting by the operator that this condition of tuning in on a particular station is brought about.

The same receiving set is shown again in Fig. 180 with one stage of audio-frequency amplification attached. Most

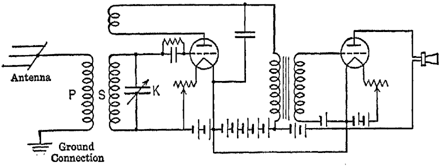

FIG. 180. Receiver of Fig. 178 with one-stage audio-frequency amplifier.

modern sets using a circuit of this kind have also a stage of radio-frequency amplification between the antenna and the detector to prevent the broadcasting of squeals produced in the set. The illustrations show only one of a great variety of receiving circuits. Also, vacuum tubes are operated from an alternating-current source by providing a modified type of filament and using a rectifier of some kind to supply plate voltage. Four- and five-electrode vacuum tubes are used in other receiving circuits.

SUMMARY OF CHAPTER VIII

The TELEPHONE and the TELEGRAPH are the principal communication devices. The telephone transmits sounds but in using a telegraph, the message must first be translated into a code.

The TELEGRAPH works much like a buzzer signal or like a combination of relay and buzzer. Additional relays called repeaters are used at intermediate points on long lines since the distance over which a single telegraph circuit can be operated is limited.

The TELEPHONE first sets up electric current waves of sizes and frequencies corresponding to the sound waves to be transmitted. After these currents are sent over the line, they cause a receiver diaphragm to vibrate thus reproducing the original sounds. Telephone repeaters using vacuum tubes are installed at intermediate points on long lines.

Telegraph messages are sent over lines used for telephone circuits by an ingenious balancing arrangement which does not allow the telegraph currents to interfere with the telephone currents.

When an electric current flows in a conductor in a certain direction, ELECTRONS, or negative particles of electricity, actually move in the opposite direction.

A VACUUM TUBE is a device in which currents of electrons pass through a space from which the greater part of the air has been removed.

A TWO-ELECTRODE TUBE acts like an electrical valve and is used chiefly in rectifier circuits.

A THREE-ELECTRODE TUBE may be used as an alternating-current generator, as a detector, or as an amplifier.

The RADIO TELEPHONE is a telephone system in which the transmission is by means of electromagnetic and electrostatic waves. Special vacuum-tube devices are used in radio sending and receiving sets.

CHAPTER IX

GENERATORS AND MOTORS

96. Definitions. It should be said in the first place that any electric motor may be run as a generator, or vice versa. If electric power is generated outside the machine and brought to it, and if this power puts the machine in motion and thus runs other machinery, the machine is called a **motor.** If, on the other hand, the machine derives its mechanical power from some source outside of itself, and delivers electric power, it is called a **generator.** The term **dynamo** includes both generator and motor.

97. Voltage Generated in Armature Wires. Fig. 181 represents the simplest form of two-pole direct-current generator or motor. As a generator, the power is delivered by the commutator C to the brushes B_1 and B_2 from which it is brought by flexible cables to the terminals A_1 and A_2.

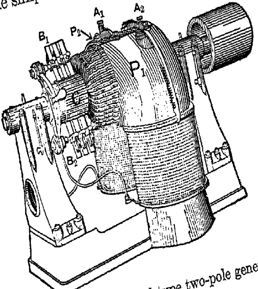

FIG. 181. Simple old-type two-pole generator.

Right here it is well to state that the electric power is not generated by the brushes rubbing on the commutator. The voltage is generated by the wires wound on the revolving armature moving near strong magnets. Fig. 182

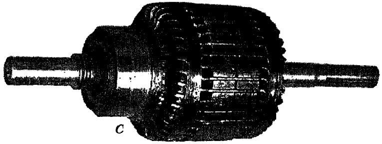

FIG. 182. Armature of Westinghouse motor or generator.

shows such an armature taken out of the frame. The wires running in slots lengthwise along it, are joined to the commutator *C*. As these wires move under the strong magnets, a voltage is set up, which tends to send an electric current through the wire. If an electric circuit is put across the brushes, this current will flow from the (+) brush through the outside circuit to the (−) brush, into the commutator, along the wires in the armature and back to the (+) brush. Fig. 183 shows a simple diagram of such an armature.

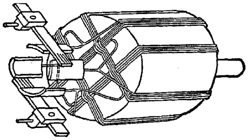

FIG. 183. Simple diagram of a drum-wound armature with commutator and brushes.

It is necessary to keep well in mind the fact that a voltage is set up in any electrical conductor which is moving across a strong magnet. If we take a simple bar magnet and move a wire quickly across the face of it, as in Fig. 184, there will be a voltage set up across the terminals of the wire which will be indicated on the voltmeter. If we now move the wire in the opposite direction

the voltmeter will indicate in the opposite direction, showing that it makes a difference in what direction the wire is moved. It is the moving of all the wires wound on the armature close to the magnetic poles of the machine which sets up the voltage. The amount of voltage that is set up depends upon the speed of the wire and the strength of the magnet. Thus, if we move a wire twice as quickly across the face of a magnet we obtain twice the voltage, or if we move it at the same speed across the face of a magnet twice as strong, we obtain twice the voltage. The high voltage of a generator is obtained by moving many wires in series very rapidly across the faces of very strong magnets.

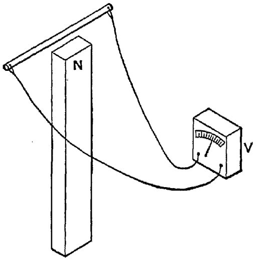

FIG. 184. When the wire is moved across the face of the magnet N a voltage is set up which is indicated on the voltmeter V.

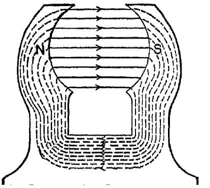

FIG. 185. Diagram of the magnetic lines in a two-pole generator.

98. Magnetic Field of a Motor. The magnetic field of the 2-pole motor in Fig. 181 is merely the field of a bar magnet bent into a horseshoe as in Fig. 185. Note that here, too, the lines come out of the north pole and enter the south pole, go through the yoke and back again to the north pole. The armature revolves in the field between the north and south poles, and the wires on it cut the magnetic lines of the field and produce a voltage across

the commutator, where it is transmitted to the brushes. Fig. 186 shows the field of a 4-pole motor. Note that the lines come out of a north pole and go into a south pole, and that north poles and south poles alternate around the frame.

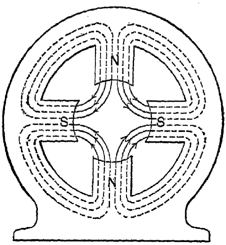

FIG. 186. Magnetic lines in a four-pole generator.

Prob. 1-9. Draw a 6-pole motor frame showing the complete paths of the magnetic lines.

Prob. 2-9. Draw an 8-pole generator frame showing the complete paths of magnetic force lines.

99. Field Coils. We have seen the important part that a magnetic field plays in a dynamo; now we will consider how this field is created.

We are all acquainted with the fact that when once a piece of hard steel has become magnetized, it remains a magnet. A piece of soft steel or iron, however, loses nearly all its magnetism as soon as the magnetizing force is removed. Now the pole pieces of dynamos are all made of soft steel or iron, and it is necessary to keep a magnetizing force present all the time.

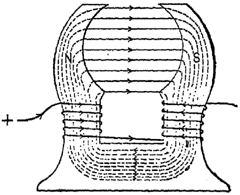

FIG. 187. The current in the coils produces the magnetic field.

It will be noted that around the pole pieces P_1 and P_2 of Fig. 181, there are wound coils of wire. These coils supply the magnetizing

force to the pole pieces. For when an electric current is sent through these coils a magnetic field is created, its direction

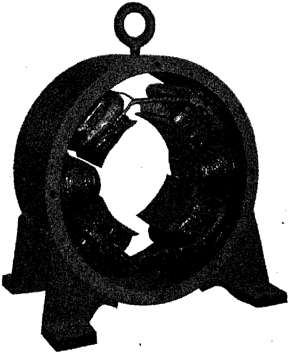

FIG. 188. A Westinghouse four-pole generator frame with pole pieces and field coils.

depending upon the direction of the electric current in the coils as discussed in section 73.

In order to produce a field as in Fig. 185, which is the field for the machine of Fig. 181, we merely have to wind coils around the pole pieces and send a current through the coils in the proper direction, as in Fig. 187.

FIG. 189. Field coil ready to be placed on pole piece.

Fig. 188 is an illustration of a 4-pole machine. Fig. 189 shows one of the field coils ready to be placed on a pole piece which is finally bolted to the frame.

Prob. 3–9. Draw the magnetic field and field coils with current for a 6-pole motor.

Prob. 4–9. Put field coils on the generator of Prob. 2–9 with field currents to produce poles as marked.

An illustration of the field of a modern 2-pole dynamo is shown in Fig. 190. The path of the magnetic lines produced by the main poles is shown in Fig. 191.

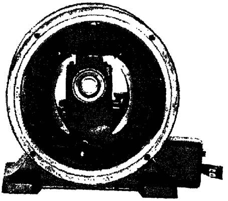

Fig. 190. Westinghouse two-pole dynamo.

In setting up a motor or generator it is necessary then to note the polarity (whether a pole is north or south) and to cause the current to flow in such a direction through the field coils as to make the poles alternately north and south.

Direct-current generators are classified as to the source from which the field coils receive their electric current. They are:

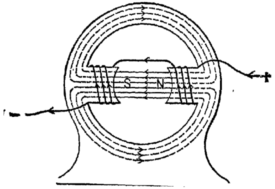

Fig. 191. Path of magnetic lines in modern two-pole generator of Fig. 190.

Separately excited, when the field current comes from some outside source, as storage cells, exciter generators, etc.

Self-excited, when the field current is drawn from the armature of the machine itself.

100. Separately Excited Field. Self-excited machines sometimes change their polarity when not in use. It is customary, therefore, to use a separately excited generator whenever it is desired that the current shall never change its direction. This point is of greatest importance in electroplating.

Fig. 192 represents the connections for a separately excited generator supplying current to a set of electroplating vats. The fields are excited from a storage battery, thus insuring a permanent polarity. Fig. 193 shows the standard way of representing a separately excited generator, connected to electroplating vats *V*.

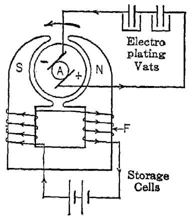

FIG. 192. Separately excited generator, supplying current to electroplating vats.

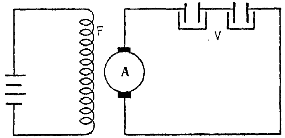

FIG. 193. Conventional diagram for Fig. 192.

101. Self-excited Field. Self-excited generators are divided into 3 classes.

Shunt. Only a small part of the current delivered by the armature goes through the field. This field current is said to be **shunted** around the main line current.

Series. All the current delivered by the armature goes through the fields before it goes out of the machine.

Compound. Two coils are supplied to each pole. One, called the shunt coil, takes a **shunted** current; the other, called the series coil, takes the full or series current. This is by far the most common type of generator.

Motor fields are classified in the same way. If the same current supplied to the motor goes through both the armature and field coils, the motor is called a **series motor.** If the current is divided, part going through each, it is called a **shunt motor.** A combination of the two is called a **compound motor.** Except in trolley cars and motors for other traction work, the shunt motor is the most common.

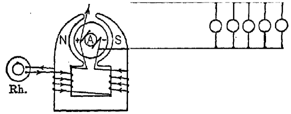

FIG. 194. Shunt generator supplying incandescent lamps with current.

102. Shunt Generator. When the fields are excited by a current shunted around the main circuit, as in Figs. 194 and 195, many turns of fine copper wire are used. In this case it is not desirable to have a large current going through the coils, because every bit thus used is really stolen from current available for the outside circuit. The resistance of the coils is therefore high. The necessary number of ampere-turns are obtained by the large number of turns which make up for the small current.

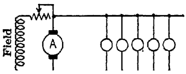

FIG. 195. Conventional diagram of Fig. 194.

103. Building Up of Shunt Field. Even when no current flows through the field coils of a machine there is always a small amount of magnetism in the field. So when we start up a shunt generator, the armature conductors are revolving in a very weak field. But as the wires of the armature cut through this weak field, a small voltage is produced across the brushes. Now, since the field coils are connected directly across the brushes (see Figs. 194 and 195), a small current will be sent through these windings. This will slightly increase the strength of the magnetic field. As the armature now revolves in this increased field, the voltage across the brushes will be raised a little, which in turn will send a larger current through the field coils, which still further increases the magnetic field, raises the voltage, and increases the field current. This is called the **building up** process of the field, and it continues until the fields have enough magnetism to produce full voltage, the value of which depends upon the speed of the armature and the resistance of the field circuit. This process usually takes from 10 to 30 seconds. After the voltage has become constant, it can be controlled further and set to any definite value within the limits of the machine, by means of an adjustable resistance in series with the field. If the voltage is too high, it can be lowered by increasing the resistance, thus lowering the field current, which weakens the magnetic field and therefore lowers the voltage produced in the armature conductors. We can also raise the voltage by increasing the speed of the armature, or lower the voltage by decreasing the speed of the armature. Then the voltage across the brushes remains constant and is ready to deliver current to the outside line.

104. Connections of a Shunt Generator. In connecting up a shunt generator, first trace back the leads from the terminals as shown in Fig. 196. Two of the leads will be found to go to the fields as the leads from the terminals

F_1 and F_2, Fig. 197. Two will be found to be connected with the brushes, as those from terminals A_1 and A_2.

Since the current in the field must come from the brushes, it is necessary to connect F_1 to A_1 and F_2 to A_2 through an adjustable resistance Rh, Fig. 198.

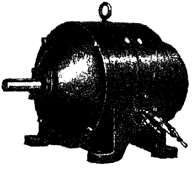

FIG. 196. Crocker-Wheeler simple shunt generator.

The line is then connected through a switch and fuses to the terminals A_1 and A_2.

Note. If the generator will not build up, reverse the field connections; that is, connect F_1 to A_2 and F_2 to A_1. If it still will not build up, excite the field from some outside source. Dry cells will often start the building-up process. If this does not work, test out the polarity and proceed as per directions in Section 126.

Prob. 5-9. The terminals of a shunt machine, when traced back, were found to be connected as marked in Fig. 199 (A–A_1 to armature and F–F_1 to field). Show connections through a field rheostat for use as a generator.

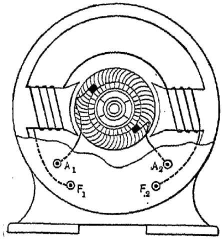

FIG. 197. Connections to terminals in generator of Fig. 196.

105. Compound Generators. Shunt generators have one fault; as soon as any current is allowed to flow from a machine into the line, the voltage falls a little and it continues to fall, as more and more current is taken. To counteract this tendency of the voltage to fall as the load rises, the load current is led through another set of coils,

called the series coils, before it is allowed to go into the line. Now the more current the line takes, the more current the series coils have, and the more strongly magnetized the

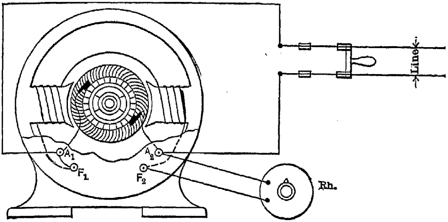

FIG. 198. Generator of Fig. 196 connected for running.

fields become. This keeps the voltage the same, no matter what current (within the limits of the machine) is taken by the line. Such a generator is called a flat-compound generator. Of course most of the magnetic lines in the field

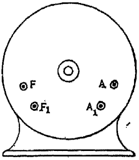

FIG. 199. A different arrangement of terminal connections.

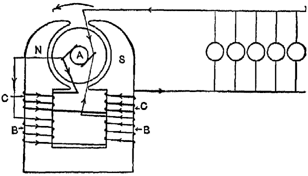

FIG. 200. A compound generator feeding incandescent lamps.

come from the current in the shunt coils; the series coils have just enough ampere-turns to increase this magnetism sufficiently to make up for the tendency of a shunt generator to lower slightly in voltage as the load increases.

In Fig. 200 the connections of a compound generator are shown, coils *C* being the series coils, and coils *B*, the shunt. Note, in Figs. 201 and 202, the two ways of connecting the shunt field of a compound generator.

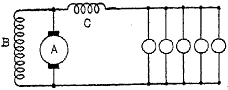

FIG. 201. Diagram of short-shunt compound generator.

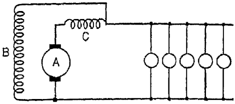

FIG. 202. Diagram of long-shunt compound generator.

Series generators are very rarely used except in series arc lighting systems.

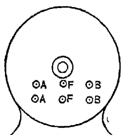

FIG. 203. Compound generator showing terminals.

Prob. 6–9. In Fig. 203, terminals *A–A* are connected to the armature, *F–F* to the shunt field coils, *B–B* to the series field coils. Show connections for a long-shunt compound generator, with a rheostat in the shunt field.

Prob. 7–9. Connect the generator in Fig. 203 as a short-shunt generator, with a rheostat in the shunt field.

106. Commutating Poles. In between the main poles, most modern machines have smaller poles called **commutating poles.** See Fig. 204. These poles are not to generate power in the armature, but merely to keep the brushes from sparking on heavy loads or high speeds. The coils on the poles are always in series with the armature, so that their strength depends upon the armature current. Due chiefly to these poles, motors are now built which will reverse at full speed and not spark at the brushes.

The polarity of the commutating poles can be found as follows: Determine the polarity of the main poles and the direction of rotation of the armature. Then if you place your hand on one pole after another, going around the

frame in the direction of rotation of the armature, any commutating pole will always have the same polarity as the

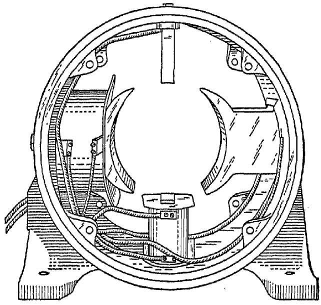

Fig. 204. Frame of two-pole generator with commutating poles.

main pole following it, if the machine is a generator; and as the main pole **behind** it, if the machine is a motor.

Note, in Fig. 205, that if we start with the north pole at the top and go around the frame clockwise (the direction in which the armature is rotating), we come next to a south interpole, which is of the same polarity as the next main pole we come to, etc.

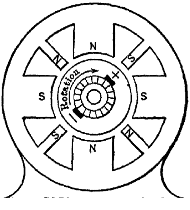

Fig. 205. Four-pole generator with commutating poles.

Prob. 8–9. Draw the field coils on the main shunt poles and commutating poles in the generator, Fig. 205, showing the direction and source of current in each coil.

Prob. 9–9. Draw same as in Prob. 8–9, making the armature rotate in the opposite direction.

107. Number of Brushes. A generator usually has the same number of sets of brushes as it has poles, not count-

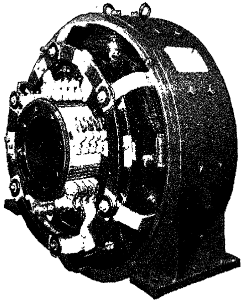

FIG. 206. Six-pole generator. *General Electric Co.*

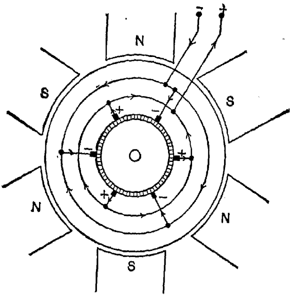

FIG. 207. Brush connection of the six-pole generator of Fig. 206.

ing commutating poles. Note that the generator in Fig. 206 has 6 poles and 6 sets of brushes. Since a machine

has but two terminals which are connected to the brushes, several of these sets of brushes must be joined together. Note, in Fig. 207, that every other brush is (+) and that all the (+) brushes are joined together in parallel and brought by leads to the (+) terminal. The remaining sets of brushes are (−) and are joined in parallel and lead to the (−) terminal.

108. Motors. Any machine which is used as a generator can be used as a motor if electric power is sent into the armature, instead of being taken from it. The current flowing in the armature conductors, acted upon by the magnetic field, causes the wire to move across the face of the magnetic pole as explained in the following paragraphs.

109. Field About a Straight Wire. When an electric current flows along a straight conductor, a circular magnetic field is formed around it as shown in Fig. 208.

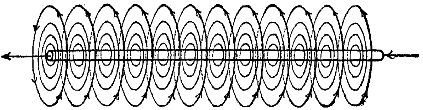

FIG. 208. The magnetic field about a straight wire carrying current.

The direction of these magnetic whirls around the wire depends upon the direction of the electric current along the wire. By noting the above figure, it will be seen that if we look along the wire in the direction of the current, the magnetic field whirls around the wire in the direction we would turn down a right-hand screw or nut. Notice in particular that these whirls are not **spirals** but are **circles**.

Fig. 209 shows a cross-section of the wire and magnetic field and represents the way the field would appear if we looked at the end of the wire with the current going away

from us. In Fig. 210 the current is reversed. Notice that the field also is reversed in direction.

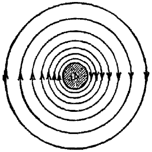

FIG. 209. Magnetic field about a straight wire: end view.

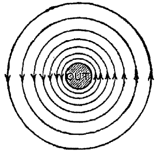

FIG. 210. Magnetic field about a straight wire: end view when the current is the reverse of that in Fig. 209.

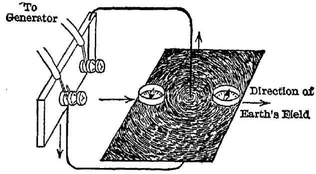

FIG. 211. The magnetic field about a wire shown by compass and

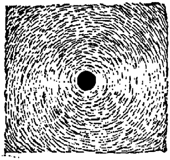

FIG. 212. Magnetic field about a wire, shown by iron filings.

Figs. 211 and 212 show this circular field about a wire carrying a current taken by means of iron filings.

110. Motor Action. In the case of a wire wound on an armature core of a motor, we have a straight wire carrying a current, placed in the magnetic field of the poles. There must then be present two magnetic fields; the circular field

around the wire, and the almost parallel field of the poles. Fig. 213 shows the result obtained by means of iron filings. The wire carrying its current is placed in the field between a north and a south pole. Note that the result is a field neither circular nor parallel, but that the lines seem to crowd together above the wire and are very much scattered below the wire.

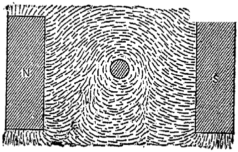

FIG. 213. The shape of the magnetic field is due to the field between the two poles and to the current in the wire.

This crowding effect of the magnetic lines above the wire tends to force the wire down into the space less crowded. So whenever a wire is placed across a magnetic field and a current is sent through it, the wire is crowded one way or the other by the combined action of the circular magnetic field around the wire and the field in which the wire is placed.

This can be further illustrated as follows: If the copper wire in Fig. 214, having no current flowing through it, is placed before the pole of a bar magnet, it will not tend to move in any direction, because magnetic lines have no action on copper. But if a current is sent through the copper wire, it will tend to move sideways. If the current is reversed, it will tend to move in the opposite direction.

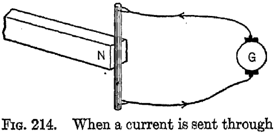

FIG. 214. When a current is sent through the wire, it tends to move sideways.

The force with which the wire tends to move depends upon the strength of the magnet and the amount of current going through the wire. If twice the current is flowing

through the wire, then there is twice the force tending to move it sideways across the face of the magnet. If the same current is sent through the wire, but a magnet twice as strong to the square inch end area is used, then the force is again twice as much.

The powerful forces exerted by motors are obtained by using many wires carrying large currents, placed near strong magnets.

It is just this action of the magnetic field of the motor on the currents in the wires of the armature that causes the armature to rotate. The wires are in the form of loops, so that the current flows in opposite directions when the wires are near opposite poles. Thus all the forces tend to pull the armature around in the same direction as will be seen by reference to Fig. 215.

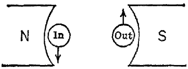

FIG. 215. When two wires carrying currents in opposite directions are near poles of opposite polarity, a turning force is produced on the wires.

111. Starting Resistance. In starting a motor of any size it is not safe to throw the full line voltage across it at once. The armature has a very low resistance, so a large current would be forced through it and would burn it up. It is therefore necessary to put a box containing an adjustable resistance, called a **starting resistance,** in series with the armature in order to cut down this current. This box is always arranged so that as the motor gets up speed, the resistance can gradually be cut out until, finally, the full line voltage is across the motor.

The reason why the full voltage will not force enough current through the armature to injure it when **running,** but will burn it up if it is **not running,** is very simple.

When the armature is revolving, the wires wound on it are cutting through a strong magnetic field and thus must be setting up a voltage in the armature, just as a generator

does. Now this voltage is always in the direction opposite to the current which is causing the motor to run, and thus limits the flow of the current. It is called the "Back Voltage," or "Counter Electromotive Force." Therefore the voltage, which at any time is forcing a current through a revolving armature, is not the voltage of the line, but **"the voltage of the line minus the back voltage in the armature."** The current, then, still obeys Ohm's Law, which may be stated as follows:

$$\text{Current (through armature)} = \frac{\text{line volts} - \text{back volts}}{\text{resistance of armature}}.$$

Of course when the armature is standing still, there is no back voltage, so the line voltage is free to act, unless a starting resistance is put in series to cut down the current.

Example 1. The resistance of the armature of a 2-horse-power motor is 0.4 ohm. What current will it take if thrown directly across 110 volts when standing still?

$$\text{Amperes (through arm.)} = \frac{\text{volts (across arm.)}}{\text{ohms (of arm.)}}$$

$$= \frac{110}{0.4} = 275 \text{ amp.}$$

This current would quickly melt the copper in the armature of a 2-horse-power motor.

Example 2. When the motor in Example 1 is running at normal speed it has a back voltage of 103 volts. What current flows through the armature when running at normal speed with 110 volts across it?

$$\text{Amperes (through arm.)} = \frac{\text{line volts} - \text{back volts (across arm.)}}{\text{ohms (of arm.)}}$$

$$\frac{110 - 103}{0.4} = \frac{7}{0.4} = 17.5 \text{ amp.}$$

Example 3. The normal current for motor in Example 1 is 18 amperes. How much resistance must be used in the starting

box so that the starting current shall not exceed $1\frac{1}{4}$ times the normal current?

$$\text{Starting current} = 1\tfrac{1}{4} \times 18 = 22.5 \text{ amp.}$$

$$\text{Resistance (of combination)} = \frac{\text{volts (of combination)}}{\text{amperes (of combination)}}$$

$$\frac{110}{22.5} = 4.89 \text{ ohms.}$$

But the armature itself has 0.4 ohm. Thus the box must have

$$4.89 - 0.4 = 4.49 \text{ ohms.}$$

Fig. 216 is a simple diagram of the starting resistance used with a shunt motor. When the line switch is thrown and C is swung to the first point, it merely puts the shunt field

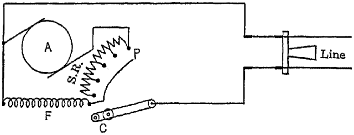

FIG. 216. Diagram of starting resistance for shunt motor.

F on to the circuit, thus building up the field immediately. Then when the arm C is swung to the next contact point, the starting resistance SR is put in series with the armature across the line. The resistance SR prevents too large a current from entering the armature. As soon as some speed is acquired by the armature (and therefore a back voltage), the arm C is swung to the next contact point, cutting out some of the resistance. As the motor gets up towards its full speed, the rest of the resistance SR is gradually cut out. Finally the armature is put directly across the line, by swinging the arm C to the point P.

Prob. 10-9. In Fig. 216 the starting resistance SR is 4.7 ohms; the armature has 0.8 ohm. What current does the armature take when starting on 110 volts?

Prob. 11–9. The field coils *F*, Fig. 216, have a resistance of 220 ohms. What current do the field coils take when on 110 volts?

Prob. 12–9. What current does the motor of Probs. 10–9 and 11–9 take when starting on 110 volts?

Prob. 13–9. The back voltage of the motor in Prob. 12–9, when running with all the starting resistance cut out, is 100 volts. What current does the motor then take?

Prob. 14–9. The armature resistance of a 4-horse-power, 220-volt motor, is 1.5 ohms. Field resistance is 450 ohms. The motor takes, when running under full load, 4.5 amperes per horse power. What starting resistance is necessary in order that the starting current shall not exceed $1\frac{1}{4}$ times the full load current?

Prob. 15–9. What must be the back voltage of the motor in Prob. 14–9 when all the starting resistance is cut out?

112. Speed Control of Shunt Motors. The shunt motor has two excellent points:

(1) Nearly constant speed at all loads.

(2) Possibility of controlling the speed by field resistance and armature resistance.

To decrease the speed of a shunt motor, resistance may be inserted in the armature circuit. This, of course, very much cuts down the power of the motor and is an expensive method of control.

To increase the speed of a shunt motor, we have only to insert some resistance in series with the field coils. It may seem strange that the weaker the field, the faster the motor goes, but such is the case. In fact, if the current is all cut out from the field of a shunt motor, the speed of the armature becomes so great that it flies apart and wrecks the machine.

But motors are now made in which the field may be weakened to a great extent and large changes in speed

effected by means of an adjustable resistance in series with the field. Such a motor is called an "Adjustable Speed Motor" and invariably is fitted with commutating poles. Unless a motor is especially designed for the work, great care should be taken to increase the armature speed but very little above the rated value.

113. No-field Release. Starting Box. To prevent the destruction of a shunt motor by the accidental shutting off of the field current, a device called a "No-field Release" is applied to the connections. This is usually combined with the starting resistance and the two form the **starting box.**

The **"no-field" release** is merely a device for shutting off all the power from a motor as soon as the field current is

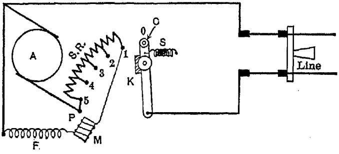

FIG. 217. Diagram of starting box with "no-field release."

broken. Thus the machine will stop rather than speed up and burst. Fig. 217 shows a device of this kind. The field current is led through a small electromagnet M on the starting box. The swinging arm C has a soft iron keeper K attached to it. When the arm has come into the running position and all the starting resistance SR is cut out, the keeper K comes in contact with the electromagnet M which holds the arm in this position, acting against the tension in the spring S.

If anything happens to break the current in the field coils F, the current in the electromagnet is also broken, and the swinging arm is released and pulled away by the

spring S. This action breaks the armature circuit and thus stops the motor.

A picture of this box is shown in Fig. 218. Note that there are but three connections to make to the box: one to **line**, one to **field** and one to **armature**. Such a box is called a **3-point box** and always has a **no-field release** device. The coil on it, therefore, must always be put in series with the field.

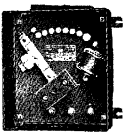

FIG. 218. Cutler-Hammer three-point starting box.

Fig. 219 shows the diagram of the inside as well as the outside connections. Let us assume that the right-hand pole of the main switch is (+), as marked, and trace the current through the box and motor. The current enters the box at the point marked "line," and

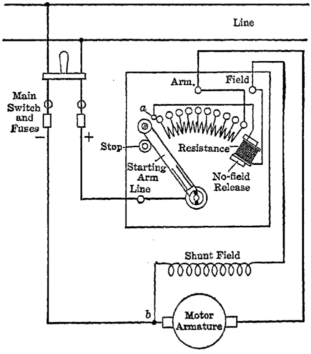

FIG. 219. Diagram of three-point starting box. "No-field" release.

goes through the swinging arm on the box. If the arm is swung to touch the point (a), the current then divides at this

point. Part of it goes through the "no-field release" coil to the point marked "field." From here it goes through the shunt field and back to the (−) side of the switch. The other part goes through the starting resistance to the point marked "arm." From here it goes through the armature of the motor and back to the (−) side of the switch.

Note that the point on the box marked "line" is connected to the line; the point marked "field" is connected

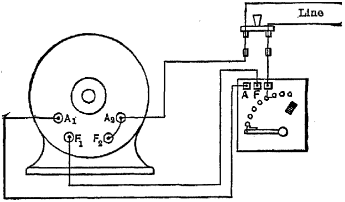

Fig. 220. Diagram of connections of shunt motor and three-point starting box.

to the field, and the point marked "arm." is connected to the armature. Thus we have one end of the line, one end of the armature, and one end of the field taken care of. The rest is just as simple. Join the other end of the armature to the other end of the field as at point (b), and then connect this juncture point to the other end of the line.

Note in Fig. 220 how the same scheme is carried out. Point L on the box is joined directly to the line switch; point F is joined to F_1 (field terminal); point A is joined to A_1 (armature terminal). Then A_2 and F_2 (other field and armature terminals) are joined together and brought directly to the other side of the line switch.

Prob. 16–9. Connect the shunt motor, Fig. 221, to the line through the starting box.

Prob. 17–9. Draw the inside connections of the box in Prob. 16–9.

Prob. 18–9. Draw the inside connections of the box in Fig. 220.

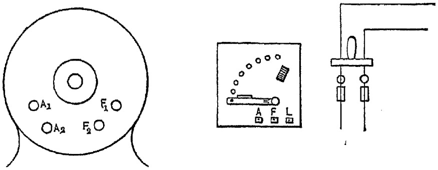

FIG. 221. Shunt motor, starting box and line.

114. No-voltage Release. Sometimes, also, there is danger that the voltage will go off the line and, a few minutes later, be thrown on again. In the meantime, the motor will have slowed down and possibly have stopped. If the voltage is now thrown on with the arm in the running position (with all the starting resistance cut out), the armature might be burned out. The above "no-field" release is designed to take care of this emergency also; that is,

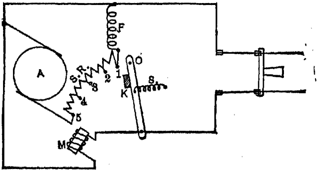

FIG. 222. Diagram of starting box with "no-voltage" release.

to release the swinging arm and throw the motor off the line, if the voltage drops.

The usual "no-voltage" release, however, is arranged as

in Fig. 222. Note that the only difference is that the coil *M* is no longer in series with the field, but is directly across the line. Thus both ends of the line must be brought to the box. This necessitates four connection points, two "line" points, an "arm." point and a "field" point. Such a box is called a **4-point box.** Fig. 223 shows the

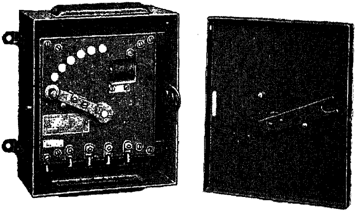

Fig. 223. General Electric four-point starting box.

appearance of a box of this type, and Fig. 224 gives the internal and external connections to the motor and line.

Assume the right-hand side of the switch to be (+) and follow the circuits through the box and motor. The current enters at the point marked "**line**" *C* and goes through the swinging arm to the button (*a*), as the arm is swung up. Here it divides into three branches, part of it going through the "no-voltage" release coil and directly to the other point marked "**line**" *B* which is directly connected to the (−) side of the line. Another part of the current goes directly to the point marked "**field,**" then through the shunt field and to the (−) side of the line. The rest of the current goes through the starting resistance to the point marked "**arm.,**" then to the armature of the motor and from there directly to the (−) side of the line.

The only difference, then, between a 4-point and a 3-point box, is the fact that in a 4-point the current through

the field does not also go through the "release" coil. This type is generally preferred, as the "release" coil does not

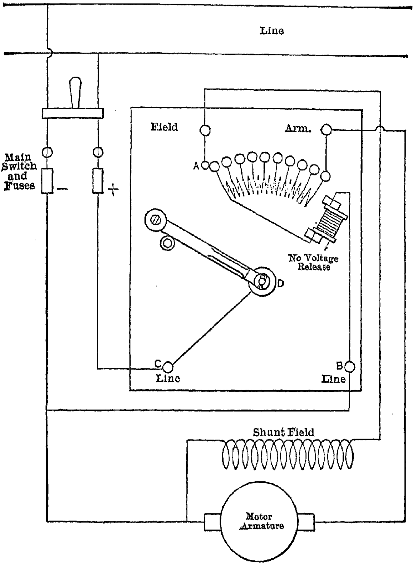

FIG. 224. Diagram of four-point starting box. "No-voltage" release.

have to carry so much current as the "release" coil on a 3-point box.

The connections to be made, then, are:

One side of		Armature	to point on box marked				"arm."
"	"	Field	"	"	"	"	"field."
"	"	Line	"	"	"	"	"line."
Other	"	Line	"	other point	"		"line."

The other armature and field ends are to be connected together and go to the side of the line not connected to the swinging arm. (On a box where it is not indicated which "line" point is connected to the swinging arm, a voltmeter placed across points C and D will not register, if D is internally connected, as in the diagram, to C; between C and B the full voltage would show up on the voltmeter, and vice versa.)

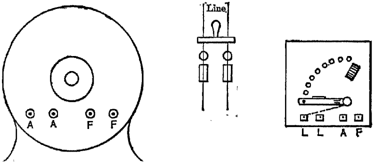

FIG. 225. Shunt motor, line and four-point starting box.

Prob. 19–9. In Fig. 225, connect the shunt motor, line and box.

Prob. 20–9. Show the internal connections of the box in Prob. 19–9.

115. Series Motor. Starting Box. The starting box of a series motor is always a 3-point box, but still always has a "no-voltage" release as is seen by Fig. 226.

Assume that the right-hand side of the switch is (+), and trace the current through the box and motor. From the (+) side of the switch two branches of the current flow. One enters A_2, goes through the armature to A_1, goes to F_1 and through the field to F_2, goes to the point on the box marked "Arm. or Field" (depending on whether (+) or (−) side of

the switch is brought to A_2 or F_2). From this point, if the swinging arm is up, a current goes through the starting resistance to the swinging arm, to the point marked "Line." From here it goes directly to the (−) side of the switch.

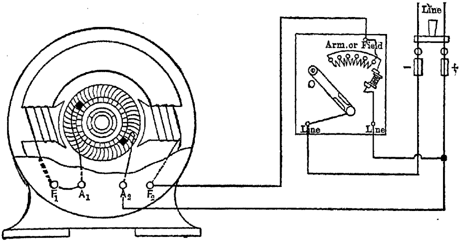

FIG. 226. The connections of a starting box for a series motor: "No-voltage" release.

The other current, starting from the (+) side of the switch goes to the other point on the box marked "Line," through the "no-voltage" release coil, through the swinging

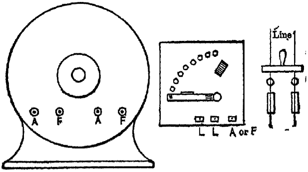

FIG. 227. Series motor, starting box and line.

arm, and back through the previous "Line" point to the (−) side of the switch.

Prob. 21–9. Connect the series motor, Fig. 227, with the line through the box.

Prob. 22–9. Show the internal connections of the box in Prob. 21–9.

Since a series motor when unloaded acts like a shunt motor with the field cut out, such a motor is never used unless geared, or directly connected, to its load, as in fans, trolley cars, hoisting cranes, etc.

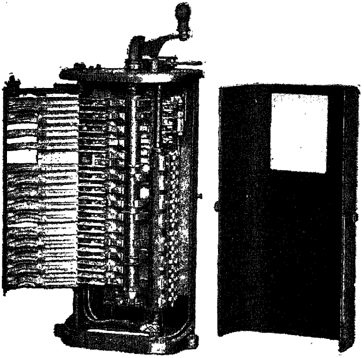

FIG. 228. General Electric drum controller for a street car.

116. Series-Parallel Control for Electric Cars. Most electric cars have at least two motors, which are of the series type. The controller shown in Fig. 228 is in the front of the car, and is operated by the motorman. It acts as a set of switches which throw out the starting resistances, etc. When the controller handle is advanced to the first notch, it places the two motors *A* and *B* in series with each other and with the starting resistance *SR*, as in Fig. 229. As the handle is advanced, it gradually cuts out the starting resistance until the car gets up a speed

of about 10 miles an hour. Then the next notch puts the two motors in parallel with each other and again in series with the resistance *SR*, as in Fig. 230. If greater speed is desired, the resistance is again cut out by still further advancing the handle.

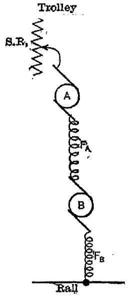

Fig. 229. The motors are in series with each other and with part of the resistance S.R.

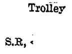

Fig. 230. The motors are in parallel with each other, but in series with part of the resistance S.R.

The scheme of putting the two motors in series at the start allows the car to be started on half the current it would take to start with them in parallel, and thus preserves a more even distribution of current in the trolley system, and wastes much less power. It really makes one motor act as a starting resistance for the other, at the same time helping it to supply tractive effort.

117. Caution in the Use of Series and Shunt Motors. A shunt motor races when the field is broken, if the armature circuit is not also broken. Therefore:

Never pull the field of a shunt motor.

A series motor races when there is no load connected to it. Therefore:

Never start an unloaded series motor and never remove all the load from a series motor while it is running.

A bad arc is formed between the first button and the contact on the arm of a starting box, if the arm is moved backwards. Stop a motor by pulling the main switch.

Never pull back the arm of a starting box.

The starting resistances are not made to carry a continuous current and will burn up if allowed to do so.

Never allow the arm of a starting box to remain more than 10 or 15 seconds on any intermediate button.

Note. Some boxes are made so that the motor can run on any point, but such boxes are always so marked.

118. "Overload" Release. There must also be some arrangement to prevent putting too much load on a motor,

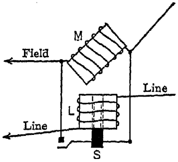

FIG. 231. Overload release of starter in Fig. 232.

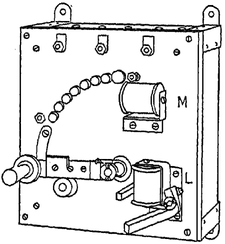

FIG. 232. General Electric starter with "no-field" and "overload" releases.

thus causing the armature current to become excessive. For the greater the load on a motor, the greater the armature current. An overload release as shown in Fig. 231 takes care

of this emergency, for a motor with a "No-field" release. A coil L of low resistance is placed in the motor line, so that all the current taken by the motor must pass through it. When the current in the motor becomes excessive, the coil be-

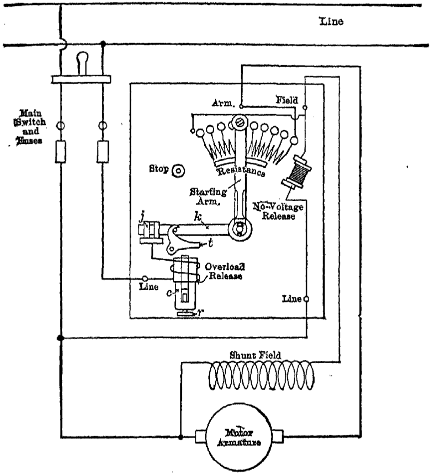

FIG. 233. Diagram of connections for motor starter with voltage" and "overload" releases.

comes so strongly magnetized that it sucks up the plunger S and short-circuits the magnet coil M. This destroys the magnetic force of M. The arm C is thus released and the current shut off from the motor armature and field. Fig. 232 shows the appearance of this box.

Fig. 233 shows another device for an "Overload" release

which will work in connection with either a " No-field " or a " No-voltage " release. The swinging arm is made up of two parts, one the starting arm, and the other the lever *k*. A spring tends to hold these together. Ordinarily the detent *t*, however, holds the lever *k* in such a position that one end is held fast in the contact clips *j*. But when the current becomes excessive, the electromagnet sucks up the iron core which is inside it, presses against the detent *t* and releases the lever *k*, which flies up out of the clip *j* and joins the starting arm. Since all the current must enter the motor through the clip *j* and the lever *k*, the power is off the motor when these are separated.

119. Signs and Causes of " Trouble." It is the purpose of the following paragraphs to discuss methods of locating and correcting troubles which appear in motors and generators after they have been put into service. It is intended to serve as a guide for men employed in installing and operating electric equipment. It is not meant for the designing room or testing department.

Certain happenings are the signs of trouble, the causes for which are more or less hidden. The expert can read these signs and go more or less directly to the cause of the trouble, just as a physician, by noting the patient's symptoms, can go more or less directly to the cause. As a rule the cause is very easy to remedy when once it has been found. The trick is to recognize the cause of the trouble from the sign. Consequently the greater stress will be laid on directions for tracing up the cause from the sign.

The following table is by no means complete, but it is believed that it covers more than nine-tenths of the troubles that are at all likely to arise. At any rate, it has this advantage, that it can be taken in at a glance, learned in an hour or so, and covers all the more common troubles.

The directions following the table show just what to do

in each case, in order to trace up the cause of the trouble, which is indicated by the sign, and repair it.

The student should be careful to make his investigations exactly in the order in which they are set down. The troubles most likely to occur are not necessarily put first, but rather the easiest to recognize and repair, the object always being to take the straightest path to the cause of the trouble, with as little interference to the service as possible.

It is to be noted in particular that these directions apply to shunt or compound machines of 110 or 220 volts only. In working around machines of higher voltage, much more care must be exercised than has been advised here to prevent electric shocks.

It will also be noted that it has been assumed that every manufacturer and user of electric power in quantity, either owns or has the use of a cheap portable ammeter and a two scale voltmeter of the same type.

DYNAMO TROUBLES

SIGNS	CAUSES
1. Sparking at Brushes.	1. Overload. 2. Brushes set wrong. 3. Poor brush contact. 4. Commutator rough or off center. 5. Weak field. 6. Armature winding broken or "short-circuited" by "ground" or " cross."
2. Noise.	1. Excessive vibration — unbalanced armature. 2. Rattle — loose parts. 3. Screeching — loose belt. 4. Flapping — loose lacing. 5. Bumping — too little end play. 6. Rubbing and pounding — armature hitting pole. 7. Squeaking — dry brushes.
3. Hot Armature Coils.	1. Overload. 2. Damp windings. 3. Short-circuited coils.
4. Hot Field Coils.	1. Too large field current. 2. Moisture in windings.
5. Hot Bearings.	1. Too little or improper oil. 2. Grit. 3. Not enough end play. 4. Belt too tight. 5. Bearing too tight. 6. Poor alignment. 7. Crooked shaft. 8. Hot commutator. 9. Rough shaft.
6. Hot Commutator.	1. Near some hotter part of machine. 2. Sparking under brush. 3. Poor brush contact.

7. Fails to build up.	1. Field connections reversed. 2. Brushes not in proper position. 3. Wrong direction of rotation. 4. Speed too low. 5. Field circuit open. 6. Not enough residual magnetism. 7. Machine short-circuited.
8. Too low voltage.	1. Too much resistance in field. 2. Overload. 3. Brushes too far forward. 4. Speed too low. 5. Some reversed poles. 6. Some poles short-circuited.
9. Too high voltage.	1. Too strong field. 2. Brushes too far backward. 3. Speed too fast.
10. Motor fails to start.	1. Wrong connections. 2. Open circuits in connecting wires. 3. Field weak. 4. Overload. 5. Friction excessive.
11. Too high speed.	1. Too much field rheostat resistance. 2. Brushes too far forward. 3. Connections wrong. 4. Open-field circuit.
12. Too low speed.	1. Overload. 2. Too little field resistance. 3. Brushes set wrong. 4. Excessive friction. 5. "Short" or "ground" in armature.

120. SPARKING AT BRUSHES

This may be due to any one or all of the following causes:

Test for and correct in the following order:

1. Overload.
2. Brushes set wrong.
3. Poor brush contact.
4. Commutator rough or off center.
5. Weak field.
6. Armature winding "open" or "short-circuited."

(1) To Test for Overload.

First: If the machine is a **generator** note the ammeter reading. If it is above the rating of the machine:

Make a rough estimation of the current taken by all appliances on the line. If the estimate agrees with the ammeter, the only remedy is to cut out some of these appliances. (Sometimes a slight shifting of brushes in the direction of rotation will help the machine to carry the load.)

Second: If the appliances call for much less than the ammeter reading, test for a ground as follows: Attach one terminal of a lamp or of a voltmeter to one line wire and the other terminal to a connection to the ground, such as a water pipe, gas pipe, etc. If the lamp glows brightly, or the voltmeter reads the voltage of the line, this means that the other line wire has a direct connection to the ground somewhere. Find this and repair it so that the voltmeter does not read when connected between either wire and the ground. A perceptible reading of the voltmeter, when attached to either line wire and the ground, shows wrong conditions somewhere. In this case, the line and fixtures should be gone over thoroughly, special lookout being kept for contacts and places that appear warm to the hand.

If the voltmeter shows no ground in the first test, look for leaks across some appliance, as a lamp socket, from one side to the other. This can generally be detected by the heating of the fixture.

Third: If the ammeter reading is not above the capacity of the machine, there still may be leaks, or grounds near or at the machine. If the machine is a motor, an ammeter inserted in series with it will tell when it is overloaded. If the overload is due to the machinery it is driving, the belt will have a tendency to squeak and be very taut on the tight side.

Fourth: Stop the machine and feel of the armature coils. If they are all too warm for the hand, it is a sure sign of overload on the machine, though there may be an overload which would not heat the coils.

If the overload is due to friction in the motor itself, the ammeter will show that a large current is taken by the motor, when it is run with its load disconnected. This "no load" current should not be more than 7 or 8 per cent of the full load current.

To find and correct this friction, see page 255 for "Elimination of Noises."

(2) **To Test Setting of Brushes.** Rock the brushes slowly back and forth to see if a place can not be found where the sparking is much less. Look for a mark made at the factory, indicating the correct position. Do not rock the brush of a machine with commutating poles.

(3) **To Test for Poor Brush Contact.**

First: Note the appearance of the commutator. It should have a clean smooth chocolate color.

Second: See that the brushes bear evenly over all their bearing surfaces. Brushes which do not, should be ground with sand paper till they fit the curvature of the commutator.

Third: Press each sparking brush separately. Note whether or not it fits its holder. Test the tension of the spring, noting whether tightening or loosening diminishes sparking.

(4) To Test for Rough Commutator. Touch the commutator, when running, with the tip of your finger nail and see if any roughness is felt. If so, stop the machine and examine the commutator. See if the mica insulating strips project above the copper commutator segment, or if a commutator bar has been loosened and become higher than the others. Note any rough spot due to the fusing effect of some momentary overload. Sandstone shaped to the curve of the commutator or sandpaper held in a wooden block, curved to fit the commutator, will remedy any of the above troubles. **Never use emery on a dynamo.**

Note. If grooves are worn in the commutator, or if it has become so much off center that the brushes move up and down as it revolves, it should be turned down, in a lathe or with a "truing" attachment. Plenty of end play will prevent grooves.

(5) To Test for Weak Field.

First: The speed will be excessive if the machine is a motor. The sparking will be worse in starting. A weak field is very likely due to wrong connections. Test the poles with a compass, using the shunt coils only. Then also using the series coils only. The poles should be alternately north and south around the frame.

Second: Broken circuit in a field coil (affecting all coils).

Test a motor by disconnecting the brushes, and suddenly opening the field circuit. If no spark appears, the circuit is open. Test by disconnecting the field from the line. Try to send the current from a few cells in series with an ammeter through each

coil separately as in Fig. 234. If the ammeter does not read when the arrangement is across any coil, it means that this coil is open.

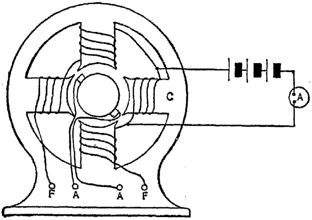

FIG. 234. Testing a field coil for an open circuit. If the ammeter does not read the field coil (c) is open.

Third: There may be a short circuit in one field coil (affecting one pole only).

To test for this: Hold a piece of iron, like a screw driver, near one pole after another. The pole which is weak probably has a short-circuited coil. Or send a current through all field coils and measure the voltage across each coil separately. If the voltage across any coil is low, it means that that coil is short-circuited.

To remedy these defects, it is usually necessary to rewind the coil.

(6) To Test for an Open- or Short-Circuited Armature Coil.

First: Short circuits in armature coils can usually be located by noting that some of the windings are very warm after a run. This should usually be suspected as the cause, if the sparking is at one point only on the commutator. A more exact method of

locating the coil is to connect a low voltage across the brushes when the machine is still, as in Fig. 235. Then touch adjacent segments all around the commutator with the two ends of voltmeter leads, using the low scale connections on voltmeter. The short-circuited coil will be between the two segments on which there is no reading, or a very low one.

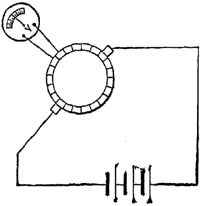

FIG. 235. Test for a short circuit in an armature. Coil is short-circuited if voltmeter reads very low.

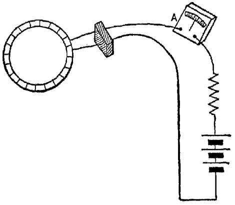

FIG. 236. Test for open armature coil. A coil is open if the ammeter reads lower than when connected across the other coils.

Second: If the sparking is due to a break in the coil, it will be violent and will always occur at one place on the commutator. To test for an open coil, disconnect the brushes and send a low current through the ammeter and one coil after another as shown in Fig. 236. Two metal strips, separated by a wooden block and spaced to touch one segment each and span one gap, make a desirable pair of terminals. If the ammeter shows very much lower reading when the metal strips are across any two segments, then the coil which is connected between these two segments is open. Usually the only remedy for a break or a ground in a coil is to take the coil off and either rewind it or replace it by a perfect coil.

121. NOISE

All machines hum and vibrate a little, but when there are any unusual noises, such as those listed below, there is something wrong with the machine. This should be investigated and corrected.

1. Excessive vibration.		1. Poor alignment or unbalanced armature.
2. Rattle.		2. Loose parts.
3. Screeching.		3. Loose belt.
4. Flapping.	Means.	4. Poor belt fastenings.
5. Bumping against bearings.		5. Collar or coupling set wrong.
6. Rubbing and pounding.		6. Armature hits poles.
7. Squeaking.		7. Brush trouble.

(1) Vibration. Put your hand on the frame and, if the machine vibrates badly, change the speed, if possible (pro-

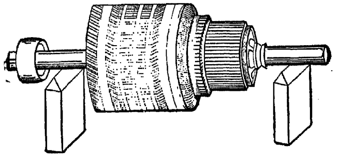

Fig. 237. Testing the balance of an armature.

viding it does not disturb other running conditions). If the machine still vibrates badly, change the alignment of one bearing. If the noise is not now stopped, change the other bearing. As a last resort, take the armature out and balance it on two knife edges as in Fig. 237. Roll it gently, setting it several times with different parts uppermost. If it always tends to come to rest with the same part down, it means that the armature or pulley is not properly balanced. It can often be fixed by screwing nuts to the light side of the

pulley or armature core. If this does not correct it, an expert must be sent for.

(2) **Rattle.** Look the machine over for loose nuts or other parts and tighten them.

(3) **Screeching.** A loose belt slips and makes a screeching noise. Tighten it. If it still slips, there is too much load for a pulley of the size used.

(4) **Flapping.** Poor lacing or loosened ends of belt flap when the loose place hits the pulley face. Stop the machine, examine the belt fastenings and repair them.

(5) **Bumping Against Bearings.**

First: Note whether or not this is due to the collar striking the bearing as the armature shaft travels back and forth lengthwise. If this is the cause, stop the machine and set the collar to allow more end play.

Second: If the machine is direct-connected to another, the pounding is probably due to poor alignment of the machines. When the machine is running, hold a pencil firmly fixed and gradually bring it near a smooth place on the coupling until it just touches. If on stopping the machine the mark made is found not to extend all around the coupling, it means that the coupling **bulges** at the point where the pencil touched. The machine should be realigned to force this point in a very little.

(6) **Rubbing and Pounding.** This is likely to be due to the armature rubbing on some pole face. Stop the machine and examine the pole face and the surface of the armature. If the armature winding is found to be loose, rebind it. If the bearing babbitt is worn so that the armature is not in the center of the field gap, rebabbitt the bearings and adjust the armature to center by noting the clearance near each pole. It may be necessary in some cases to file the pole faces.

(7) Squeaking. This noise is generally due to one or more of the brushes.

First: Try lifting off one brush at a time (providing this does not open the circuit). Find the brushes which make the most noise, and readjust the tension, seeing that the brush holder allows for proper play.

Second: Apply a little vaseline with the finger to the commutator when running.

Third: Be sure that the brushes are set at the correct slant for the direction of rotation of the armature and that they fit the curvature of the armature. This curvature can be obtained by holding a strip of sandpaper firmly on the armature and turning the armature back and forth, letting the sandpaper wear down the brushes. On large machines, pull the sandpaper between the brush and armature, holding the brush firmly against the paper. The brushes on new machines always squeak more or less at first, but this should stop after running a day or two.

122. HOT ARMATURE COILS

When there is an odor of hot insulation about a machine, it is always well to stop the machine and feel of the armature coils. Heating may be due to some of the following causes:

Test for and correct as directed below:	1. Overload. 2. Dampness in coils. 3. Short-circuited coils.

(1) To Test for Overload. As on pages 250 and 251, for "sparking."

(2) To Test for Dampness in Coils. Look for any steaming of coils, and stop the machine and feel of the coils. If damp, bake in an oven or, better, send nearly full current through the armature for several hours. (Turn the armature slowly meanwhile.)

(3) **To Test for a Short-Circuited Coil.** See page 253 for "sparking."

123. HOT FIELD COILS

Heating of the field coils is usually due to one of the following causes:

Test for and correct in following order:	1. Too large current in coils. 2. Dampness in coils.

(1) **To Test for Too Large Field Current.**

First: Feel of all coils. If they are all hot, it means that the field current must be reduced, usually by means of field rheostat. If any coils are cool, it means that the cool ones are probably short-circuited.

Second: To be certain, measure the voltage across each coil. If any coil measures much lower than the others, take it off and look for a short circuit.

(2) **To Test for Dampness in Coils.** Note whether or not the coils steam, or feel damp to the hand. If so, send about three quarters of the full current through them for several hours.

124. HOT BEARINGS

If there is a smell of burning oil, or if the bearings are too hot for the hand to be held on them, then any of the following causes may be present:

Test for and correct in following order:	1. Too little oil of proper kind. 2. Grit in oil. 3. Not enough end play. 4. Belt too tight. 5. Bearing too tight. 6. Poor alignment. 7. Crooked shaft. 8. Hot commutator. 9. Rough shaft.

(1) **Oil Cups not Working.** Be sure all oil cups are full and delivering oil to the bearing, or that the oil rings rotate freely and bring up oil. (The oil may not be of the right quality and, as a last resort, should be changed on the advice of an expert.)

(2) **Grit in Oil.** See that the oil is free from grit by rubbing a little oil between the fingers. If not, stop the machine, clean the shaft and bearing thoroughly, and put in clean oil.

(3) **Not Enough End Play.** If the shaft collar keeps bumping against the bearing, there is not enough end play allowed for the armature "to pull into its field." Stop the machine and set the collar further from the bearing.

(4) **Belt Too Tight.** Make certain that the belt is not so tight that it draws the shaft too hard against the bearings.

(5) **Shaft Too Tight in Bearings.** Loosen the cap of the bearings, and see if the bearing runs cooler.

(6) **Poor Alignment.** Loosen the lower bearing a little, allow it to take a new position and note whether or not the bearing runs cooler. If the machine is direct-connected to another, the alignment of the two machines with respect to each other may be poor. Note whether or not the coupling runs true, using the test on page 256. If not, make new alignment and test until the coupling does run true.

(7) **Crooked Shaft.** Observe the armature for evidences of wobbling, which means that the shaft is crooked. Stop the machine if this appears to be the trouble, and test, turning the armature by hand. This trouble can be remedied only by getting a new shaft from the manufacturing company.

(8) **Hot Commutator.** Stop the machine and feel of the commutator and bearing. If the commutator is evidently hotter than the bearing, the heat probably comes from the

commutator. This trouble can be eliminated according to directions given below for hot commutators.

(9) **Rough Shaft.** While the machine is still, take off the cap and examine the shaft and bearings. If either shaft or bearing is rough, smooth it with a fine file.

125. HOT COMMUTATOR

A hot commutator may be due to one of the following causes:

Test for and repair in the following order:

1. Being near some hot part of machine.
2. Sparking under brushes.
3. Poor brush contact.

(1) **Test for Hotter Part.** Place your hand on the bearing near the commutator. If this is hotter than the commutator, heat comes from there, and it should be looked after according to directions given above.

(2) **Test for Sparks Beneath Brushes.** Sight between the brush and commutator and see if there are not a number of small sparks passing. If there are, apply the above methods for stopping sparks.

(3) **Test for Poor Brush Contact.**

First: Test the tension of the brushes by pulling up one after another (being careful not to open the circuit) and correct any defects.

Second: Note, by taking out the brush and examining the worn places on the contact surface, whether or not the brush is bearing on the commutator with its full face. If not, sandpaper the high spot down and fit the surface to the commutator as directed on page 251.

Third: If the commutator seems dry, apply a little vaseline to it with the finger tip.

126. GENERATOR FAILS TO BUILD UP

This is always due to the failure of the magnetism in the field to "build up," which may usually be traced to one of the following causes:

Test for and correct in the following order:

1. Reversed field connections.
2. Brushes in wrong position.
3. Wrong direction of rotation.
4. Speed too low.
5. Open field-circuit.
6. Not enough residual magnetism.
7. Machine short-circuited.

(1) Test for Reversed Field Connections. Reverse the connections of field to armature. (For the reason, see page 221.) If this does not cause the voltage to rise to the normal value, replace the connections as before.

(2) Test for Position of Brushes. While the machine is running, shift the brushes very slowly through their maximum arc. Replace the brushes to the mark made by the manufacturer, if the trouble is not corrected. Never shift the brushes of a machine having commutating poles.

(3) Test for Direction of Rotation. Reverse the direction of rotation of the armature. If this does not correct the trouble, change back again to the former direction.

(4) Test for Too Low Speed. Take the speed of the shaft with a speed counter or indicator and compare with the rated speed of the machine as a generator. Note that the same machine must run much faster as a generator than as a motor. Try the effect of higher speed.

(5) Test for an Open Field-Circuit.

First: Stop the machine and disconnect the armature. Send a current from a battery through the field. If there is not a good spark when the circuit is now broken, it means that there is a break in the field circuit.

Second: Test each field coil in the same way, or as in paragraph 120, page 252, and find where the break is. If the break is on the inside of any coil, this coil must be replaced or rewound.

(6) Test for Low Residual Magnetism. Connect up the machine as at the start, but leaving open one field connection A to the armature, Fig. 238. Connect in a few dry cells so as to send a current through the field while this connection A to the armature is open. Start the machine and, if the voltage begins to pick up when the remaining field connection is made, pull the dry cells out. If not, try connecting the cells to send the current in the reverse direction through the fields.

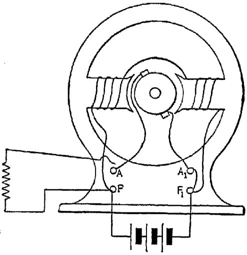

FIG. 238. Test for low residual magnetism.

(7) Test for Short Circuit of Machine.

First: Pull the line switch. This disconnects all load from the machine. If the generator now "builds up," throw the line switch. If the voltage does not die out again, it means that there was too large a starting load on the machine. If there is a short circuit on the line, the circuit-breaker will trip, or the fuses will blow as the load is thrown on. This trouble should be located and corrected according to the directions on page 251 before voltage is again thrown on the line.

Second: If the machine fails to "build up" with the line switch open, there is probably a short circuit at the machine. Stop the machine and place

Note. Two grounds are necessary to make a short circuit. When it is found that a ground exists in either the armature or the field circuit, before removing the coils, be sure that the trouble is not at the terminals.

127. VOLTAGE OF GENERATOR TOO LOW

This may be due to any of the following causes, most of which produce a weak field.

Test for and correct in the following order:

1. Too much resistance in field.
2. Overload.
3. Brushes placed wrong.
4. Speed too low.
5. Reversed poles.
6. Pole " short-circuited."

(1) Too Much Resistance in the Field.

First: Cut out gradually all resistance of the field rheostat.

Second: Look for a loose or corroded field connection.

(2) Test for Overload. See page 250, for overload producing " Sparking at brushes."

(3) Test for Position of Brushes. Shift the brushes a little against the rotation of the armature, especially if the generator has commutating poles.

(4) Test for Too Low Speed. See page 261, on low speed as a cause for failure to " build up."

(5) Test for Reversed Poles. In multipolar machines, test each pole with a compass. Poles should alternate north and south around the frame. Reverse the connections on any poles found to be of wrong polarity.

(6) Test for a Short-Circuited Field Coil. See page 253, or test of short circuit in case of " hot field coils."

Note. Two grounds are necessary to make a short circuit. When it is found that a ground exists in either the armature or the field circuit, before removing the coils, be sure that the trouble is not at the terminals.

127. VOLTAGE OF GENERATOR TOO LOW

This may be due to any of the following causes, most of which produce a weak field.

Test for and correct in the following order:

1. Too much resistance in field.
2. Overload.
3. Brushes placed wrong.
4. Speed too low.
5. Reversed poles.
6. Pole " short-circuited."

(1) Too Much Resistance in the Field.

First: Cut out gradually all resistance of the field rheostat.

Second: Look for a loose or corroded field connection.

(2) Test for Overload. See page 250, for overload producing " Sparking at brushes."

(3) Test for Position of Brushes. Shift the brushes a little against the rotation of the armature, especially if the generator has commutating poles.

(4) Test for Too Low Speed. See page 261, on low speed as a cause for failure to " build up."

(5) Test for Reversed Poles. In multipolar machines, test each pole with a compass. Poles should alternate north and south around the frame. Reverse the connections on any poles found to be of wrong polarity.

(6) Test for a Short-Circuited Field Coil. See page 253, or test of short circuit in case of " hot field coils."

128. GENERATOR VOLTAGE TOO HIGH

This may be due to any of the following causes:

Test and correct in the following order:	1. Field too strong. 2. Brushes in wrong position. 3. Speed too fast.

(1) Test for Too Strong Field. Gradually cut in all of the field rheostat resistance.

(2) Test for Brush Position. Shift the brushes a little in the same direction as the armature rotates, especially if the generator has commutating poles.

(3) Test for Speed. Take the speed with a speed counter or indicator and compare with the speed rating of the machine. If possible, lower the speed.

129. MOTOR FAILS TO START

If the motor does not start when the arm of the starting box reaches the third point, pull the main switch and release the arm. Failure may be due to the following causes:

Test for and correct in order given:	1. Wrong connections. 2. Open circuits. 3. Weak field. 4. Overload. 5. Friction excessive.

(1) Wrong Connections. Go over all connections carefully, being sure that they agree with the diagrams and principles given in the earlier part of this chapter. Note especially the connections to the starting box, if it is an unfamiliar make. Be sure that there is no load on the motor.

(2) Test for Open Circuits.

First: With the line switch closed, place a voltmeter across the line between the fuses and machine. If it does not indicate, look for blown fuses, open circuit breakers, etc.

Second: Put a voltmeter across the armature terminals, and try starting the motor, as before, not exceeding 3 points on the box, if motor does not start. If the voltmeter does not read, there is either a wrong or a broken armature connection.

Third: Put a voltmeter across the field terminals, and try starting the motor, not exceeding 3 points on the box if motor does not start. If the voltmeter does not read, there is either a wrong or a broken field connection. If the voltmeter reads the apparently correct values, proceed with the following tests.

(3) **Test for Weak Field.** Cut out all resistance in the field rheostat.

(4) **Test for Overload.** Remove the load and try starting the motor. Put the load on slowly. If the fuses or circuit breakers blow, the load is too heavy.

(5) **Test for Friction.**

First: Start the motor with the load off, putting an ammeter in the motor line. If the current taken by the motor is more than 6 or 8 per cent of the full load current, there is too much friction present.

Second: Continue the test as on page 251 in tests for overload of motors producing "sparking at brushes."

130. MOTOR SPEED TOO HIGH

This is usually due to a weak field. It may have any of the following causes:

Test for and correct in order given:	1. Too much field-rheostat resistance.
	2. Brushes too far forward.
	3. Connections wrong.
	4. Open field-circuit.

(1) **Test for Rheostat Resistance.** Cut out all the resistance for the shunt field rheostat.

(2) **Test for Position of Brushes.** Shift the brushes against the direction of rotation especially if the motor has commutating poles.

(3) **Test for Wrong Connections.** Go over all connections and make them agree with the directions in sections 113–118.

(4) **Test for Open Field-Circuit.** An open field-circuit makes an unloaded shunt motor race and spark badly. With the armature leads disconnected, put voltage across the field terminals. If there is no spark when the circuit is now broken, there is an open circuit in the field. (See test for location of break on page 252, in "Test for Weak Field.")

131. MOTOR SPEED TOO LOW

This fault may be due to the following causes:

Test for and correct in order given below:	1. Overload. 2. Field resistance too small. 3. Brushes set too far backward. 4. Excessive friction. 5. Short circuit in armature.

(1) **Test for Overload.** Test as on page 251, for "Overload."

(2) **Test for Too Small Field Resistance.** Cut in more resistance on the field rheostat.

(3) **Test for Brush Setting.** Shift the brushes a little forward, especially if the motor has commutating poles.

(4) **Test for Excessive Friction.** Test as on page 266, for "Excessive Friction."

(5) **Test for Short Circuit in Armature.** Test as on page 253, "for Short or Ground in Armature Circuit."

SUMMARY OF CHAPTER IX

GENERATOR — a machine delivering electric power when mechanical power is put into it.

MOTOR — a machine delivering mechanical power when electric power is put into it.

DYNAMO — a term which includes both motor and generator. The same machine may be used either as a motor or as a generator.

VOLTAGE is generated by wires wound on the armature cutting through a magnetic field; the brushes merely convey it to the outside line.

MAGNETIC FIELDS are produced by winding soft iron or steel with coils and sending an electric current through the coils.

THE POLES of a machine should be alternately North and South around the frame, and their strength depends upon the number of AMPERE-TURNS in the coils.

FIELD may be either:

- SEPARATELY EXCITED — when the field current comes from some outside source. This type is rarely used.
- SELF-EXCITED — when the field current comes from the armature of the machine itself.

SELF-EXCITED generators are divided into:

- SHUNT — when only a small part of the current going through the armature goes through the field coils.
- SERIES — when all the current going through the armature flows through the field as well as the line.
- COMPOUND — when two coils are used on each pole, one a series coil, and the other a shunt coil. This is the most common type of generator

MOTORS are classified in the same manner as self-excited generators. Shunt motors are in most common use except for traction work.

VOLTAGE OF A GENERATOR must be "built up" from the small amount of residual magnetism left in the frame since last used. The voltage of a shunt generator can be controlled by means of an adjustable resistance inserted in the field cir-

cuit, which varies the field current and therefore the magnetic strength. When once "built up" and set at proper value by field resistance, the voltage of a shunt generator is nearly constant. It can be made absolutely constant by means of series coils in addition to the shunt coils.

COMMUTATING POLES are small poles on both generators and motors for the purpose of preventing sparking at the brushes. The coils on these poles consist of a few turns of heavy wire, and are always placed in series with the armature so that the same current flows through them as through the armature.

The polarity of commutating poles is determined as follows: Determine the polarity of the main poles; then place your hand on one pole after another in order, around the frame, in the direction in which the armature is to rotate. Every commutating pole will have the same polarity as the main pole which follows it, if the machine is a generator; or as the main pole just behind it, if the machine is a motor.

A machine generally has the same number of brushes as poles, not counting commutating poles. All (+) brushes are in parallel and all (−) brushes are in parallel.

RULES FOR PUTTING A GENERATOR INTO SERVICE. Follow back the leads from all terminals. Draw a sketch of the machine with leads and terminals marked as found. Make a diagram of the necessary connections and then follow the diagram.

Connect the terminals so that the series coils and the coils on the commutating poles are in series with the armature and main line switch.

Connect the shunt coils through the rheostat so that they are across the armature (or across armature and series coils if long shunt).

Be sure the coils give correct polarity. This can be tested by a compass using the shunt set along and then the series set with very light load.

THE TURNING TENDENCY OR TORQUE in a motor armature is due to the action of the magnetic field on the armature conductors when they are carrying a current.

IN STARTING a motor, a resistance must be placed in series with the armature, because of the low resistance of the armature.

A BACK VOLTAGE is set up as the armature gets in motion, which opposes the flow of current in the armature to such an

extent that the starting resistance can be cut out. Ohm's Law for this case can be stated:

$$\text{CURRENT (through armature)} = \frac{\text{LINE VOLTS (across armature)} - \text{BACK VOLTS (in armature)}}{\text{RESISTANCE (of armature)}}.$$

SPEED OF A SHUNT MOTOR can be INCREASED by inserting resistance in the field circuit. The weaker the magnetic field, the faster the speed. Fitted with this device the motor is an Adjustable Speed Motor. Such motors generally have commutating poles.

Can be DECREASED by resistance in series with the armature.

A NO-FIELD RELEASE is used on a shunt motor because the motor will speed up and wreck itself if the field happens to be destroyed. Consists of a coil on the starting box, in series with the field of the motor, which throws the motor off the line when anything happens to the field.

A NO-VOLTAGE RELEASE is often used on any kind of motor, which will throw the motor off the circuit if the voltage of the line drops below a certain point. This prevents the line voltage, as it comes on again, from being thrown across the motor after it has stopped. Consists of a coil directly across the line and not in series with the field.

A THREE-POINT STARTING BOX for shunt motors has three terminals and contains starting resistance and "No-field" release. Terminal marked "Field" is to be connected to the field terminal on the motor. The terminal marked "arm." is to be connected to the armature terminal on the motor. The terminal marked "Line" is to be connected to one side of the line. The other side of the line goes to the other armature and field terminals on the motor.

A FOUR-POINT STARTING BOX has four terminals and is fitted with a "No-voltage" release. The extra terminal is connected to the line on the same side as the common armature and field connection on the motor.

A SERIES MOTOR "races" when it is unloaded and is therefore always attached to its load. Series motors are used mostly in traction work.

The two series motors of a trolley car are started in series with each other. The motorman by means of controller grad-

ually cuts out resistance, then throws the two motors in parallel with each other, but again in series with the resistance. The final step cuts out the resistance and each motor is put directly across line.

AN OVERLOAD RELEASE automatically throws the motor from the line when the armature is carrying so much current that it is likely to burn. It consists of an electromagnet in the motor line, which works a tripping device if the current through it reaches a certain fixed value.

TO REVERSE THE DIRECTION OF ROTATION of a motor, reverse the direction of the current in EITHER the field or the armature, NOT IN BOTH.

CAUTION. Do not cut out current from the field of a shunt motor.

Do not start an unloaded series motor or take off the load of a series motor while running.

Do not stop a motor by pulling back the arm of the starting box. Pull the main switch or circuit breakers.

Do not allow the arm of a box designed "for starting duty only" to remain on intermediate points.

Note carefully the SIGNS of trouble. Make tests for the CAUSES of trouble in the order given. By this method one cause after another is eliminated and the final cause is certain to be found.

TO AVOID TROUBLE.

First: Keep the commutator clean. The load which a machine will carry and the length of time for which it will carry the load is, as a rule, limited by the sparking and heating of the commutator and brushes. It is of prime importance, then, to keep the commutator clean and smooth and the brushes well fitted both to commutator and brush holder, so that they may work under the best possible conditions.

Second: Keep all parts of an electric machine dry.

PROBLEMS ON CHAPTER IX

Draw diagrams of the electrical connections before making computations.

Prob. 23–9. A shunt generator with a brush voltage of 115 volts delivers 42 amperes to the line. The field coils have a resistance of 180 ohms.

(*a*) What current flows through the field?

(*b*) What current flows through the armature?

Prob. 24–9. What power does the generator of Prob. 23–9 deliver?

Prob. 25–9. What power is used to excite the fields of the generator in Prob. 23–9?

Prob. 26–9. The short-shunt compound generator of Fig. 201 maintains 110 volts across the terminals. The series field has a resistance of 0.25 ohm. The shunt field has a resistance of 250 ohms. Each lamp takes 2 amperes.

(*a*) How much current flows in the shunt field?

(*b*) How much current flows in the series field?

(*c*) How much current flows in the armature?

Prob. 27–9. How much power is lost in the series field of the generator of Prob. 26–9?

Prob. 28–9. How much power is lost in the shunt field of the generator of Prob. 26–9?

Prob. 29–9. The resistance of the armature of the generator in Prob. 26–9 is 0.24 ohm. How much voltage is required just to send the current through the armature?

Prob. 30–9. How much power is lost in the armature of Prob. 29–9?

Prob. 31–9. If the generator of Prob. 26–9 were connected as long shunt, answer (*a*), (*b*) and (*c*) of Prob. 26–9.

Prob. 32–9. How much power is lost in the series field of the generator of Prob. 31–9?

Prob. 38–9. In the compound generator of Fig. 243, *FF* represent the shunt field terminals, and F_1F_1 the series field terminals. Are the connections right for a long shunt? If not, make the necessary changes.

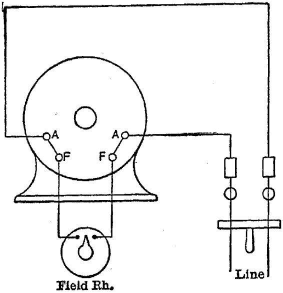

FIG. 242. Are these connections correct?

Prob. 39–9. Connect the generator of Prob. 38–9 as a short-shunt compound generator.

Prob. 40–9. Connect the generator in Fig. 243 as a simple shunt generator.

Prob. 41–9. If the shunt generator of Fig. 241 failed to "build up" after it was connected according to a correct wiring diagram, what change in the connections would you make?

Prob. 42–9. Connect the generator in Fig. 240 to run as a motor.

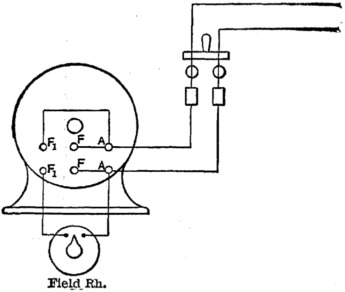

FIG. 243. Connections of compound dynamo:

Prob. 43–9. Make the necessary changes in your diagram of connections for Prob. 42–9, to reverse the direction of rotation of the motor.

Prob. 38–9. In the compound generator of Fig. 243, FF represent the shunt field terminals, and F_1F_1 the series field terminals. Are the connections right for a long shunt? If not, make the necessary changes.

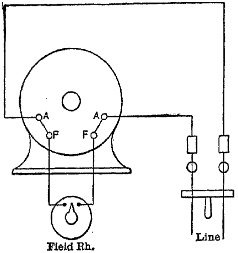

FIG. 242. Are these connections correct?

Prob. 39–9. Connect the generator of Prob. 38–9 as a short-shunt compound generator.

Prob. 40–9. Connect the generator in Fig. 243 as a simple shunt generator.

Prob. 41–9. If the shunt generator of Fig. 241 failed to "build up" after it was connected according to a correct wiring diagram, what change in the connections would you make?

Prob. 42–9. Connect the generator in Fig. 240 to run as a motor.

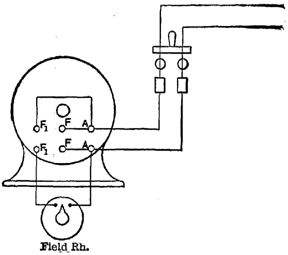

FIG. 243. Connections of compound dynamo:

Prob. 43–9. Make the necessary changes in your diagram of connections for Prob. 42–9, to reverse the direction of rotation of the motor.

Prob. 44–9. Connect the generator of Fig. 241 to run as a motor. (" No-field " release on the box.)

Prob. 45–9. Show the necessary changes in the connections for motor of Prob. 44–9 to reverse the direction of rotation.

Prob. 46–9. Connect the generator of Fig. 242 to run as a motor. (" No-voltage " release on the box.)

Prob. 47–9. Show the necessary changes in your connections for Prob. 46–9, to reverse the direction of rotation.

Prob. 48–9. Connect the generator in Fig. 243 to run as a shunt motor. (" No-voltage " release on the box.)

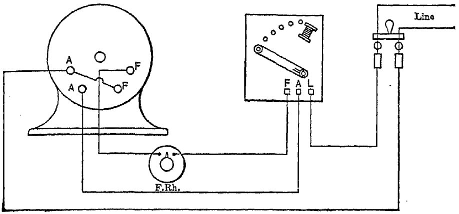

FIG. 244. Motor with rheostat and starting box.

Prob. 49–9. Is the shunt motor of Fig. 244 connected correctly? If not, make the necessary changes.

Prob. 50–9. Make the necessary changes in your diagram of connections for the motor of Fig. 244, to reverse the direction of rotation.

Prob. 51–9. Make a diagram showing a 220-volt shunt motor connected through a " No-voltage " release box and field rheostat to a 3-wire system.

Prob. 52–9. Change the connections on the diagram of Prob. 51–9 so that the fields will be excited by 220 volts, and the armature by 110 volts.

Prob. 53–9. Change the connections on the diagram of Prob. 52–9 so that the fields will be excited by 110 volts and the armature by 220 volts.

Prob. 54–9. State the effect on the speed of the motor of:

(*a*) Changes made in Prob. 52–9.
(*b*) Changes made in Prob. 53–9.

Prob. 55–9. Make a diagram of the connections ot tne motor in Prob. 52–9, showing the necessary addition to the outfit and connection, if the motor speed was too high, and you were not allowed to use the 110-volt connections.

Prob. 56–9. Show a magnetic path in the commutating pole motor, Fig. 245, with 2 main poles. Mark the polarity of the commutating poles.

Prob. 57–9. Show the winding of all poles of the motor in Fig. 245, and the direction of current in the windings.

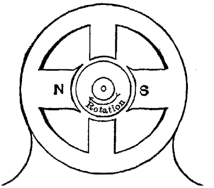

FIG. 245. Diagram of pole structure of two-pole motor with commutating poles.

Prob. 58–9. If the machine in Fig. 245 is to run as a self-excited shunt generator, show:

(*a*) Polarity of commutating poles, and direction of armature rotation.
(*b*) Path of magnetic lines.
(*c*) Direction of current in windings on poles.
(*d*) Connections of windings on poles.

Prob. 59–9. What size rubber-covered copper wire must be run from the generator in Prob. 23–9, in order to meet the Underwriters' rules?

Prob. 60–9. When the generator of Prob. 59–9 is delivering full load, what is the " drop " along 400 ft. of main line?

Prob. 61–9. If it is desired to make the " drop " along 400 feet of the line wire half what it is in Prob. 60–9, what size copper wire should be used?

Prob. 62–9. What size aluminum wire should be used in Prob. 59–9?

Prob. 63–9. How much power is lost in the 400 feet of line wire in Prob. 60–9?

Prob. 64–9. If double the voltage were used in Prob. 60–9 to

transmit the same power, how many watts would be lost in the 400 feet of line wire?

Prob. 65–9. The line voltage is 112 volts. The resistance of the shunt field F, Fig. 217, is 200 ohms; of magnet coil M, 20 ohms. In the starting resistance SR the resistance from 1 to 2 is 5 ohms; from 2 to 3, 4 ohms; from 3 to 4, 3 ohms; from 4 to 5, 1 ohm; armature resistance is 2 ohms. The switch to power is thrown and contact c is swung to point No. 1.

(*a*) How many amperes flow through the armature?
(*b*) How many amperes flow through the field?

Prob. 66–9. When the armature of Prob. 65–9 has attained enough speed to set up a back voltage of 25 volts, the contact c is swung to point 2.

(*a*) How many amperes flow through the armature?
(*b*) How many amperes flow through the field?

Prob. 67–9. When the back voltage of armature in Prob. 66–9 is 48 volts, contact c is swung to point 3.

(*a*) How many amperes flow through the armature?
(*b*) How many amperes flow through the field?

Prob. 68–9. The armature of Prob. 67–9 attains a back voltage of 102 volts and contact c is swung to point 4. Answer (*a*) and (*b*) of Prob. 67–9.

Prob. 69–9. Armature of Prob. 68–9 attains a back voltage of 106 volts and contact c is swung to point 5. Answer (*a*) and (*b*) of Prob. 67–9.

Prob. 70–9. Armature resistance, Fig. 222, is 3 ohms. Field resistance is 224 ohms. Resistance of starting box is divided as follows:

1 to 2	2 ohms.
2 " 3	2 "
3 " 4	3 "
4 " 5	= 2 "
M	= 1000 ohms.

Voltage of line = 115 volts.

(*a*) What is the starting current of the motor?
(*b*) If the back voltage of the motor is 75 volts when running on point 2 of the starting box, what current is the armature then taking?

Prob. 71–9. If the motor in Prob. 69–9 takes 3 amperes when running on point 4, what is its back voltage?

Prob. 72–9. A shunt motor takes a total current of 80 amperes from 115-volt mains. The resistance of the armature is 0.04 ohm. Resistance of field is 60 ohms.

(*a*) What current does each take?

(*b*) What power is lost in the field and armature?

Prob. 73–9. (*a*) What is the total power taken by the motor in Prob. 72–9? (*b*) Why is this greater than the power lost in the field and armature as computed in Prob. 72–9?

Prob. 74–9. What current does the field take in Prob. 70–9 (*a*) and (*b*)?

CHAPTER X

METERS AND INSTRUMENTS

132. Definitions. The American Institute of Electrical Engineers classifies electrical measuring devices under two general heads. An **instrument** is a " device which measures the present value of the quantity under observation." Ammeters, voltmeters, and wattmeters are the more common electrical instruments and according to these definitions are not meters at all. A **meter** is a device which registers, through a totalizing mechanism, the product of the quantity to which it responds and the time of response. The most common example is the watt-hour meter, the speed of which depends upon the watts and the reading upon the product of watts and hours.

133. The Milliammeter. One type of current-measuring instrument operates on the same principle as the electric motor. In Figs. 246 and 247, the permanent horseshoe magnet with poles N and S supplies the field and a few turns of fine wire AB form the armature winding. The two coil springs W keep the pointer at the zero position when no current flows in the movable coil. Suppose, in Fig. 247, the current flows away from the reader along side B and toward the reader along side A. As explained on page 229 in connection with motor action, the clockwise circular field around B strengthens the field of the permanent magnet NS **above** the wires B and weakens it **below**. This urges side B **downward**. In the same way the counter-clockwise field about A strengthens the magnet's field **below** A and weakens it **above**. Thus A is urged **upward**. These two actions cause the coil to turn against the tension of the springs W. The

stronger the current flowing through the coil, the stronger the turning force.

Now at the factory, after the springs have been put in place, the instrument is connected into a circuit containing

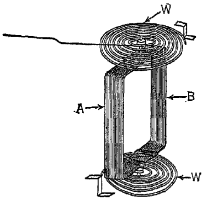

FIG. 246. Diagram showing coil AB, springs W and pointer of electrical measuring instrument.

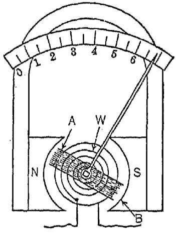

FIG. 247. Diagram showing essential parts of milliammeter.

a standard instrument which covers the range of the one being calibrated. A **blank** scale is put in place as shown in Fig.

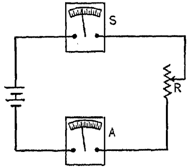

FIG. 248. Standard instrument S is used to calibrate the ammeter A.

248, and if, for instance, the instrument happens to be an ammeter with a range of 0–7 amperes, the current is changed by means of rheostat R, until the standard ammeter S reads

exactly 1 ampere. This point is marked on the blank scale of the ammeter *A*. The handle of the rheostat *R* is now turned until the standard instrument reads 2 amperes and then a second point is marked on the blank scale. This process is continued for each ampere up to the limit of the scale. An expert marker now completes the scale markings dividing the 1-ampere intervals into smaller intervals. The ammeter *A* has now been calibrated to read correctly the current flowing through it.

Instruments of this type are usually built so sensitive that a very small current indeed flowing through the coil will give full-scale deflection. For instance, the current required for full-scale deflection might be 0.025 ampere or 25 milliamperes. (A milliampere is one-thousandth of an ampere.) In this case the scale would be marked in divisions from 0 to 25 and would indicate milliamperes. Such an instrument is called a **milliammeter.**

The reading of this type of instrument is always determined by the current in its movable coil. That is, its pointer will always indicate 25 milliamperes when 25 milliamperes flow in the movable coil, or it will indicate 10 milliamperes when 10 milliamperes flow in the coil.

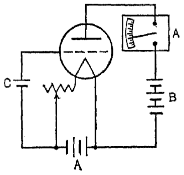

FIG. 249. Milliammeter used to measure plate current of a vacuum tube.

Example 1. A milliammeter is used to read the plate-circuit current of a large vacuum tube and is connected as shown in Fig. 249. The apparent resistance from plate to filament is 30,000 ohms, the resistance of the instrument 9 ohms and the voltage of the B battery 700 volts. What is the plate current?

The resistance of the instrument (9 ohms) and of the battery and connecting wires can be neglected as compared with 30,000 ohms of the tube. By Ohm's Law the current through the milliammeter is

$$\frac{700}{30{,}000} = 0.0233 \text{ ampere or } 23.3 \text{ milliamperes.}$$

The instrument just described could be used to measure this current since it will safely measure currents up to 25 milliamperes.

Prob. 1–10. What is the voltage drop across the instrument described in this section when measuring 25 milliamperes? The resistance of the instrument coil is 9 ohms.

Prob. 2–10. What power is being lost in the instrument coil under the conditions of Prob. 1–10?

Prob. 3–10. What power is being lost in the coil of the instrument described above when it is indicating 10 milliamperes?

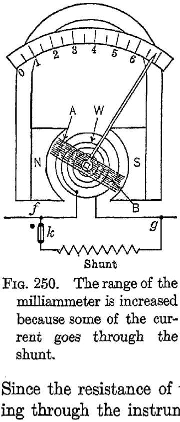

FIG. 250. The range of the milliammeter is increased because some of the current goes through the shunt.

134. The Ammeter. The instrument just described can be used to measure any magnitude of direct current if it is provided with a **shunt** as shown in Fig. 250. This shunt or resistor is chosen of such size that it takes a large or small proportion of the total current as the case may require, thus causing full-scale deflection for a larger total current than without the shunt. For example, suppose the instrument described in the previous section is provided with a 9-ohm shunt. Since the resistance of the coil is 9 ohms, any current flowing through the instrument from f to g will divide at f, half of it going through the coil and half through the shunt. Full-scale deflection will occur when the total current is 50 milliamperes, and in any case, the actual current being measured is twice the reading.

Suppose again that the shunt has a resistance of 1 ohm

and the coil 9 ohms as before. Full-scale deflection will occur when 0.025 ampere flows in the coil. By Ohm's Law the voltage drop across the coil is $0.025 \times 9 = 0.225$ volt. This voltage exists also across the shunt and will force $\frac{0.225}{1} = 0.225$ ampere through the shunt. The total current through the instrument is the sum of the currents through the coil and through the shunt or $0.025 + 0.225 = 0.25$ ampere or 250 milliamperes. That is, when the instrument reads 25 milliamperes, 250 milliamperes are actually being measured. When provided with a switch K, Fig. 250, to disconnect the shunt this milliammeter is given two ranges, 0–25 milliamperes when the switch is to the left (open) and 0–250 milliamperes when the switch is to the right (closed).

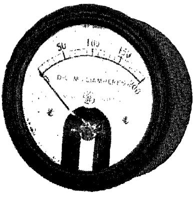

FIG. 251. A milliammeter with a 200-ampere range. *General Electric Co.*

If the shunt has a much smaller resistance than those already considered, say $\frac{1}{111}$ ohm, the full-scale reading corresponds to a current many times that in the coil. For full-scale deflection the drop is $0.025 \times 9 = 0.225$ volt as before. But the current in the shunt is now

$$\frac{0.225}{\frac{1}{111}} = 24.975 \text{ amperes,}$$

and the total current through the instrument is the sum of the currents through the coil and through the shunt or $0.025 + 24.975 = 25$ amperes. The milliammeter with a range of 0–25 milliamperes with this particular shunt, then, becomes

an ammeter with a range of 0–25 amperes. The total currents are, for all deflections, 1000 times the currents in the coil.

Example 2. What would be the range of this instrument if the resistance of the shunt is $\frac{1}{11}$ ohm?

For full-scale deflection the voltage is, as before, $0.025 \times 9 = 0.225$ volt.

The current in the shunt is $\dfrac{0.225}{\frac{1}{11}} = 2.475$ amperes.

The total current is $0.025 + 2.475 = 2.5$ amperes. The range is then 0–2.5 amperes.

Notice that in all but the first of these examples, the shunts have been chosen in such a way that the total current is 10, 100 or 1000 times the current in the coil. In these cases the same scale can be used for an instrument having two or three ranges. If the ranges do not differ by multiples of 10, separate scales are usually provided for the different ranges.

From the examples just considered we may deduce the method of finding the resistance of the shunt required to multiply the readings by any desired factor. To multiply by 10, the resistance of the shunt was $\frac{9}{10-1}$; to multiply by 100, the resistance of the shunt was $\frac{9}{100-1}$, by 1000, $\frac{9}{1000-1}$ and in general the

$$\textbf{resistance of shunt} = \frac{\textbf{resistance of coil}}{\textbf{multiplier} - 1}$$

Note that the resistance offered by the coil and shunt of an ammeter is always low. Hence the **Caution. Do not connect an ammeter across the line.**

Prob. 4–10. A milliammeter has a full-scale deflection of 100 divisions when the coil current is 10 milliamperes. The coil has a resistance of 15 ohms. (*a*) What size of shunt must be used to give this instrument a range of 0–10 amperes? (*b*) A range of 0–1 amperes? (*c*) Show a 2-point switch for the purpose of changing from one range to the other.

Prob. 5–10. What would be the range of the instrument in Prob. 4–10 if the shunt had a resistance of 0.0685 ohm?

Prob. 6–10. What would the resistance of a shunt have to be if it were to be used with the instrument of Prob. 5–10 to give it a range 10 times as great?

135. Voltmeter. We noticed that when we used the milliammeter of section 133 to measure current, the drop across its terminals was $0.025 \times 9 = 0.225$ volt at full-scale deflection. Also, for half-scale deflection there would be $\frac{0.025}{2} \times 9 = 0.1125$ volt across its terminals. If then we supply another scale marked millivolts in addition to the one marked milliamperes and make 225 millivolts correspond to 25 milliamperes, 112.5 millivolts to 12.5 amperes, etc., this instrument could be used as a **millivoltmeter** to measure small voltages.

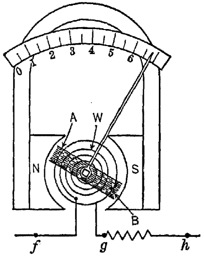

FIG. 252. The milliammeter becomes a voltmeter when the series resistor is added.

If larger voltages are to be measured, a **series** resistor is connected as shown in Fig. 252, and is of such size as will give the proper range. Suppose we wish to use this same instrument as a **voltmeter** using the same scale to indicate 250 volts on full-scale deflection. The drop across the coil will be 0.225 volt when the current is 0.025 ampere. The total drop across coil and resistance in series is to

be 250 volts. This leaves $250 - 0.225 = 249.775$ volts across the resistor. The resistor must have $\frac{249.775}{0.025} = 9991$ ohms. As a check we may now work backwards and find that the current which will flow through the instrument when 250 volts are impressed on it is

$$\frac{\text{volts across instrument}}{\text{total resistance of instrument}} = \frac{250}{9991 + 9} = 0.025 \text{ ampere}$$

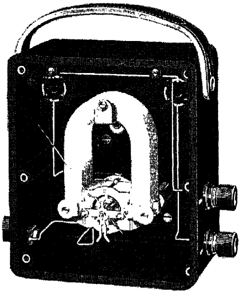

FIG. 253. Interior of voltmeter showing arrangement of series resistors for two ranges. *Jewell Electrical Instrument Co.*

which as we know gives full-scale deflection. Thus we have made the 25-milliampere milliammeter into a 250-volt **voltmeter** by adding a series resistance of 9991 ohms.

Or, using another form of Ohm's Law,

$$\frac{\text{volts across instrument}}{\text{full-scale current}} = \text{series resistance} + \text{resistance of coil.}$$

$$\frac{250 \text{ (volts)}}{0.025 \text{ (ampere)}} = 9991 + 9 \text{ (ohms)}$$

The series resistance to be added to give a full-scale deflection on a certain voltage can be found by dividing this voltage by the full-scale current and then subtracting from this quotient the coil resistance; thus

$$\textbf{series resistance} = \frac{\textbf{full-scale volts}}{\textbf{full-scale coil current}} - \textbf{coil resistance}$$

$$= \frac{250}{0.025} - 9 = 9991 \text{ ohms.}$$

Example 3. What size series resistor should be used with the above instrument to give full-scale deflection on 2.5 volts?

$$\text{Series resistance} = \frac{2.5}{0.025} - 9 = 100 - 9 = 91 \text{ ohms.}$$

A portable voltmeter with 2 scales is shown in Fig. 254 and the arrangement of the series resistors inside the case can be seen in Fig. 253.

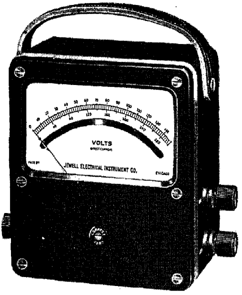

FIG. 254. Exterior view of voltmeter of Fig. 254 showing two scales. *Jewell Electrical Instrument Co.*

Prob. 7–10. What series resistance must be added to the milliammeter of Prob. 4–10 to make it indicate 100 divisions when placed across a 100-volt line?

Prob. 8–10. What would be the range of the instrument of Prob. 4–10 if it had a resistor of 45.5 ohms in series with its coil?

Prob. 9–10. Show a diagram of connections for series resistors arranged to give a milliammeter 2 different voltage ranges. What would be the sizes of these series resistors if the instrument of Prob. 4–10 is to be equipped for 15- and 75-volt scales?

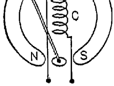

FIG. 255. Diagram of simple watch-case ammeter or voltmeter.

136. Iron Vane Instruments. A very sturdy type of construction for ammeter or voltmeter is shown in Fig. 255. Inexpensive watch-case instruments are similar to this type, as they will stand a lot of abuse. Around the inside of the case extends a circular permanent magnet with poles N and S. Directly between these poles is an oval piece of soft iron set in bearings

and carrying the pointer. When no current flows in coil C, the oval piece of soft iron is held in a horizontal position, but when a current flows in the coil the magnetic field is distorted, thus turning the piece of soft iron around. The coils of ammeters of this type have few turns of very heavy wire. Voltmeters have many turns of fine wire.

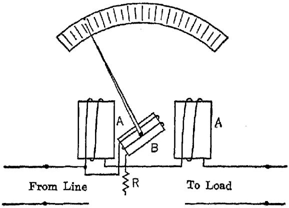

FIG. 256. Diagram of wattmeter.

137. The Wattmeter. Power can be measured by a device called a **wattmeter** which is really a combination of ammeter and voltmeter. Fig. 256 shows the arrangement of one of these instruments. The coils A–A carry the current of the load and supply a magnetic flux in the same way as do the field windings of a motor. The movable coil B carries a current proportional to the voltage across the line.

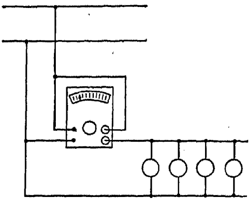

FIG. 257. Wattmeter connected to measure power taken by lamp load.

Thus, with a magnetic field proportional to current and an armature current proportional to voltage, the turning force

is proportional to both, that is, to the power or the product of the load amperes and the load volts.

Example 4. Each of the lamps in Fig. 257 takes 1 ampere at 112 volts. What does the wattmeter read?

The current in the current coil (right-hand terminals) of the wattmeter is $4 \times 1 = 4$ amperes and the voltage across the voltage coil (left-hand terminals) is 112 volts.

The power consumed by the lamp load is the reading of the wattmeter $= 112 \times 4 = 448$ watts.

Prob. 10–10. Show the connections of a wattmeter like the one in Fig. 257 to measure the power taken by the armature of a shunt motor.

Prob. 11–10. Show the connections of a wattmeter to measure the power lost in the field of a shunt generator.

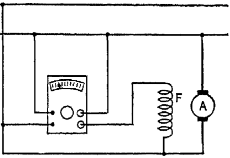

FIG. 258. What power does the wattmeter measure?

Prob. 12–10. Does the wattmeter of Fig. 258 measure the power taken by the motor? If not what does it read?

Prob. 13–10. Reconnect the wattmeter of Fig. 258 to read the total power delivered to the motor.

138. The Watthour Meter. If, instead of the movable coil *B*, Fig. 256, a coil of fine wire equipped with a commu-

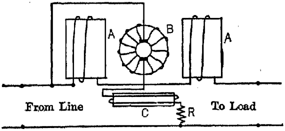

FIG. 259. Diagram of watthour meter.

tator is allowed to revolve between the current coils *AA* as shown in Fig. 259, and if this rotating coil is connected

across the line, the turning force acting on B is always proportional to the product of volts and amperes or to the watts of the load. Such an arrangement is used in the **watthour meter**, the rotating armature being geared to a set of dials which register the number of kilowatt-hours.

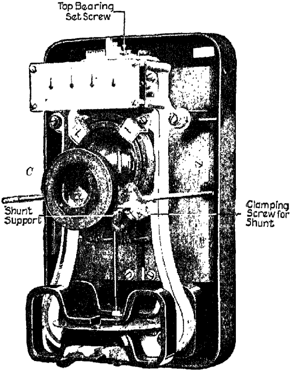

FIG. 260. Direct-current watthour meter with cover removed. *General Electric Co.*

In order that the speed of the armature shall be proportional to the watts it is necessary to provide a retarding force proportional to the speed. This retarding force is provided by the magnetic brake, composed of permanent magnets and the disc at the lower end of the shaft (see Fig. 260).

To show that the meter registers kilowatt-hours, let us assume that the volts across the line are 110 and that there are 2 amperes in the current coils. The power is $2 \times 110 = 220$ watts or 0.220 kilowatt. Suppose that for this power the armature speed is 1100 revolutions per hour. In 5

hours the armature makes $5 \times 1100 = 5500$ revolutions. Through the gear mechanism the dials register $5 \times 0.220 = 1.1$ kilowatt-hours.

Now if the load were doubled, that is, if the current were 4 amperes instead of 2 amperes the power would be $4 \times 110 = 440$ watts or 0.44 kilowatt. Twice the power means that the armature runs twice as fast and makes 2×1100 revolutions in 1 hour or 11000 revolutions in 5 hours. Thus the meter will register twice as much as in the first case or $5 \times 0.44 = 2.2$ kilowatt-hours.

Consider now that the load is the same as in the first case but that this load is required for 20 hours instead of for 5. The meter runs at the same speed as in the first case but 4 times as long and therefore registers $4 \times 1.1 = 4.4$ kilo-watt-hours. Thus we see that this meter registers the product of kilowatts and the hours these kilowatts are used.

The small coil C is provided to compensate for friction at slow speeds. If not properly adjusted it may make the meter "creep" when no current flows through the current coils.

Prob. 14–10. A certain watthour meter has marked on its aluminum disc $K = 0.2$ meaning that 0.2 watt-hour of energy is passed through the meter every time the armature makes a complete revolution. By means of a stop watch it was found that there were 45 revolutions of the armature in 60 seconds. (*a*) How much energy was passed through the meter in 5 hours? (*b*) What power did the load consume?

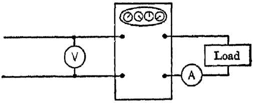

FIG. 261. Connections for checking the reading of a direct-current watthour meter.

Prob. 15–10. The meter of Prob. 14–10 is checked for accuracy by connecting a voltmeter and an ammeter as shown

Prob. 19–10. What will be the full-scale current when the shunt of Prob. 18–10 is used with the instrument of Prob. 17–10?

Prob. 20–10. The instrument of Prob. 17–10 is to be provided with 2 ranges 0–25 amperes and 0–250 amperes. What must be the resistances of the shunts?

Prob. 21–10. The 25-ampere ammeter of Prob. 20–10 is used directly across a dry cell to get a momentary test for short-circuit current. It indicates 24 amperes. What is the internal resistance of the cell if its e.m.f. is 1.5 volts?

Prob. 22–10. What current would flow if in Prob. 21–10 a wire were put directly across the terminals without the ammeter?

Prob. 23–10. Repeat Probs. 21–10 and 22–10 with a cheap ammeter having a resistance of 0.02 ohm.

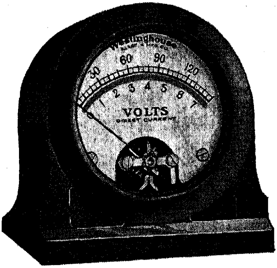

FIG. 262. Westinghouse voltmeter with two scales.

Prob. 24–10. If the two-range voltmeter of Fig. 262 has a resistance of 100 ohms per volt on each of its scales, what is its resistance in each case?

Prob. 25–10. What current does the voltmeter of Prob. 24–10 take when measuring (*a*) 25 volts, (*b*) 90 volts, and (*c*) 150 volts?

Prob. 26–10. What current does the voltmeter of Prob. 24–10 take when measuring (*a*) 2 volts, (*b*) 5 volts, and (*c*) $7\frac{1}{2}$ volts on its lower scale?

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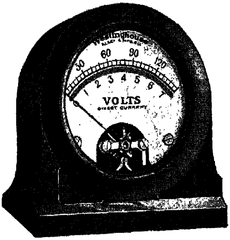

FIG. 262. Westinghouse voltmeter with two scales.

Prob. 24–10. If the two-range voltmeter of Fig. 262 has a resistance of 100 ohms per volt on each of its scales, what is its resistance in each case?

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Aluminum Wire

To find the **resistance** per 1000 ft. of a certain size aluminum wire, multiply the resistance per 1000 ft. of that size copper wire by 1.64.

To find the **weight** of 1000 ft. of a certain size aluminum wire, multiply the weight per 1000 ft. of that size copper wire by 0.30.

TABLE II
Resistance per Mil-foot

Material (Commercial)	Ohms per mil-foot at 20° C.
Aluminum	17.1
Copper, annealed	10.4
Copper, hard-drawn	10.65
Iron, annealed	90
Iron, E. B. B. (Roebling)	64
German silver 18% nickel	200
German silver 30% nickel	290
Manganin	250 to 450
IA IA (Boker) soft	283
IA IA (Boker) hard	300
Advance (Driver-Harris)	294
Nichrome	600
Calorite	720

TABLE III
Average Current taken by D. C. Motors

Horse power	Amperes on 110-volt line	Amperes on 220-volt line	Horse power	Amperes on 110-volt line	Amperes on 220-volt line
$\frac{1}{4}$	3	1.5	25	186	93
$\frac{1}{2}$	5.4	2.7	30	222	111
1	9	4.5	35	260	130
2	17	8.5	40	296	148
3	25	12.5	50	...	185
5	40	20	60	...	220
$7\frac{1}{2}$	58	29	75	...	275
10	76	38	85	...	312
15	114	57	100	...	366
20	150	75			

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10	76	38	85	...	312
15	114	57	100	...	366
20	150	75			

TABLE IV

Safe Carrying Capacities of Copper Wires

Gage No.	Diameter (d) in mils	Area (d^2) in circular mils	Rubber insulation amperes	Varnished cambric insulation amperes	Other insulation amperes
18	40.3	1,624	3	....	5
16	50.8	2,583	6	....	10
14	64.1	4,107	15	18	20
12	80.8	6,530	20	25	25
10	101.9	10,380	25	30	30
8	128.5	16,510	35	40	50
6	162.0	26,250	50	60	70
5	181.9	33,100	55	65	80
4	204.3	41,740	70	85	90
3	229.4	52,630	80	95	100
2	257.6	66,370	90	110	125
1	289.3	83,690	100	120	150
0	325.0	105,500	125	150	200
00	364.8	133,100	150	180	225
000	409.6	167,800	175	210	275
....	.....	200,000	200	240	300
0000	460.0	211,600	225	270	325
		250,000	250	300	350
		300,000	275	330	400
		350,000	300	360	450
		400,000	325	390	500
		500,000	400	480	600

Note. Table IV gives the allowable continuous current-carrying capacities of copper wires and cables of 98 per cent conductivity, according to the standard adopted by the American Institute of Electrical Engineers. For aluminum wire the allowable carrying capacities shall be taken as 84 per cent of those given in the table for the respective sizes of copper wire with the same kind of covering.

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